No. 2. — *A Visit to the Bermudas in March,* 1894. By ALEXANDER AGASSIZ.

GENERAL DESCRIPTION.

BEFORE completing my article on the Bahamas I was anxious to visit the Bermudas. During my visit I chartered a sea-going tug, and was thus able in a comparatively short time to cover every interesting spot on the shores of the islands and on the inner and outer ledge flats. During the spring of 1894 I spent about a month in their examination,[1] and find that the story of their present condition is practically that of the Bahamas, with the exception that at the Bermudas we have an epitome as it were of the physical changes undergone by the Bahamas. One cannot fail to be struck with the insignificance of the corals as compared with those of Florida, of the Bahamas, and of the Windward Islands. It is true that on the ledge patches inside of the so called "ledge flats" the Gorgonians and Millepores are very flourishing, but the development of the true reef builders, of the massive corals, is insignificant; while the absence of Madrepores is remarkable, and changes the whole aspect of the coral growth.

I shall have little to add to the description of the Bermudas as given by Nelson, Rein, Thomson, Rice, and Heilprin, but I am inclined to take a different view of the part which the corals now growing there have played in the formation of the reef ledge flats. The corals have not added any material part to the reefs; they form only a thin veneer over the disintegrated ledges of æolian rock which constitute the so called reef off the south shore of Bermuda and the ledge flats of the reef ring near the outer edge of the Bermuda Bank. Æolian rock ledges underlie the coral growth not only on the patches off the south shore and on the ledge flats of the outer reef, but they also underlie the so called patches and heads forming the flats which extend on both sides of the main channel and divide the lagoons or interior waters of the bank into irreg-

[1] Notes from the Bermudas. By Alexander Agassiz. From a letter to Professor James D. Dana, dated Bermuda, March 12, 1894. American Journal of Science, 3d ser., Vol. XLVII No. 282, June, 1894.

ular sounds, like Murray Anchorage. The passage of the shore æolian rock ledges into the coral patches can easily be traced, off both the north and the south shores, as will be seen later on.

I have to thank his Excellency, the Governor of the Bermudas, General Lyon, for permission to make soundings and dredgings among these islands with the view of studying the coral formation. To the Hon. Archibald Alison, Colonial Secretary, I am indebted for assistance in many ways during my visit to the Bermudas, especially in obtaining information from the government officers, and for a fine specimen of floating pumice stranded upon the south shore; and to Captain Carr, R. N., in charge of the Bermuda dockyard, for information regarding Ireland Island and the flats. I have to thank General Russell Hastings and the American Consul, the Hon. Marshall Hanger, for their interest in my explorations, and to Mr. John C. Watlington I am indebted for statistics regarding the temperature of the sea water at different seasons of the year.

The slope of the mountain of which the Bermudas are the summit varies considerably, judging from the three sections given on Plate II. The slope off North Rock (Plate II. Fig. 3) is steeper than the slope off Castle Harbor (Plate II. Fig. 4). Off North Rock the distance from the 100 fathom line to a depth of nearly 1,400 fathoms is about six miles, while off Castle Harbor the 100 fathom line is nearly eight miles from a depth of less than 1,250 fathoms. Off the Argus Bank the 100 fathom line is about ten miles from a 1,370 fathom sounding (Plate II. Figs. 1, 2). These sections show the slope of the island to be steeper off the north face than on the south side of the island.

On the southwest face off Long Bar 1,250 fathoms is found at a distance of five miles from the 100 fathom line, and the 1,000 fathom line is only two miles from the 100 fathom line. Northeast from the East Ledge Flats 1,260 fathoms is found at a distance of five and a half miles from the 100 fathom line. South-southeast from the Southwest Breaker 960 fathoms is found two and a half miles from the 100 fathom line.

The distance of the 100 fathom line from the sea edge of the ledge flats varies but little, though it is true that off the south shore it is nearer as a whole, and it comes to within one mile and a quarter of the shore off Castle Harbor, and on the north side it is as much as three and a half miles from the North Ledge Flats, and east off Mills Breaker it is nearly five miles (Plate I.).

The Bermudas (Plate I.) form a hook-shaped line of islands, the main island running northeast from Gibbs Hill to Castle Harbor, which is bounded on the north by a chain of islands of which St. David is the most prominent, and on the east by a chain of smaller islands, the continuation of the spit east of Tuckerstown, which is the easternmost point of the main island. Outside of Castle Harbor on the north extends a chain of islands which bound St. George Harbor, the largest of which is St. George Island. Endless islets and rocks flank the south shore from Tuckerstown to Church Bay, where the main island makes a sweep to the southwest as far as Wreck Hill. It is separated by a narrow channel from Somerset Island, to the northward.

From Somerset Narrows a chain of small islands extends to the northeast, on the last of which is built the dockyard. The north shore of the main island is flanked by numerous islands, which form Hamilton Harbor, Port Royal Bay, Great Sound, and the connecting waters to the westward of Spanish Point (Plate III.). At the eastern end of the main island a narrow channel opens into Little or Harrington Sound, which covers the greater part of that end of the island. The position of the former Bermudian land is indicated by isolated rocks, like North Rock (Plate VIII.), the Pilchard Dicks, the Southwest Breaker, the South Reef, the Mills and Northeast Breakers, and others rising above the general level of the broad belt of ledge flats which completely surround the summit of the Bermuda mountain. These flats leave only here and there a narrow passage into the interior sounds, bounded by the many belts of flats crossing the inner waters. The principal passages are the Narrows, or Ship Channel, Hog Fish Cut, Chub Cut, North Rock, and Mills Breaker channels, in addition to a few insignificant boat passages. The Narrows is really the only channel navigable for heavy draught vessels.

The Lagoon, lying to the northward and northwestward of the islands, is bounded by the curve of the outer ledge flats. They are submerged at low water, except at a few points such as the North Rock, Mills Breaker, Southwest Breaker, and others marked on the chart (Plate I.). The depth of the Lagoon is in general from seven to nine fathoms, though a few of the deeper points are twelve or thirteen fathoms. Between the outer ledge flats and the islands are found the many secondary flats, called Elies Flat, Cowground Flat, Brackish Pond Flats, Green Flats, Bailey Bay Flats, Three Hill Shoals, and the like, which consist of endless patches of Millepores and Gorgonians, reaching many of them to within a few inches of the surface. The Gorgonians and Algæ which cover the patches have grown upon the remnants of ledges of the proto-Bermudian land that attest to its former existence at so many points, not only of the outer reef ledges, but on the flats intervening between them and the Lagoon (Plate XVIII.). Between these patches separated by deep water, and plainly seen by its discoloration, it is comparatively easy to find one's way when the water on the banks is not rendered milky by winds stirring up the bottom.

Lagoons similar to those between the reef and the islands are Great Sound, Port Royal Bay, Hamilton Harbor, Harrington or Little Sound, St. George Harbor, and Castle Harbor. These sounds, as the inner lagoons are called, differ from similar sinks in the outer lagoon by being bounded in part or wholly by land, while the sounds in the outer lagoon are more or less indistinctly limited by flats formed of "coral head" patches (Plate I.).

Harrington Sound is connected with the outer lagoon by a narrow channel, the Flats Inlet; it is, in fact, in the condition of many of the smaller bays on the south shore, where the sea has only comparatively lately encroached upon the interior sinks. I refer to such bays as Sinky, Hungry (Plate XV.), Devon, and the like. In the case of Little Sound, the opening at Flats Inlet broke through the ridge separating the outer lagoon from an extensive sink, the smaller elevations of which have entirely disappeared, with the exception of a few islands and shoal patches. Castle Harbor and St. George Harbor were probably similar sinks, the outlines of which are still indicated by the line of islands protecting in part the southern face of Castle Harbor, while the outline of the narrow sink forming St. George Harbor is shown by the islands which separate it from the Narrows, and by St. David and Long Bird Islands, which are the remnants of the ridge dividing St. George from Castle Harbor. But both these ridges are now broken through, so that Castle Harbor connects with St. George Harbor and on the north with the lagoon forming Murray Anchorage.

The æolian hills extending eastward from the northern entrance to St. George Harbor are most characteristic, and the saddles separating them are of varied elevations, and show how readily the sea could, after a very limited subsidence, find its way into sounds like Castle and St. George Harbors at a time when they probably appeared much like the nearly closed Harrington Sound (Plate V.).

As Professor Heilprin has stated, it is merely a question of time when Harrington Sound will be more of an open bay than of a land-locked lagoon, presenting in time the appearance of Castle Harbor, and finally perhaps that of Great Sound.

An examination of the chart (Plate I.) reveals faintly the position of similar lagoons, the limiting land of which has been entirely washed away. Such are the three small lagoons situated in the flats to the south of East Ledge and to the west of Mills Breaker, showing channels leading into them from the bank similar to the Narrows which lead from the edge of the bank to the lagoon forming Murray Anchorage. A number of such open lagoons facing south are found extending into the inner edge of the reef flat, to the eastward and westward, directly south of North Rock, as far west as the Eastern Blue Cut. On the outer face of the reef south of Western Blue Cut, at the Chub Cut, the Chub Heads, and between High Point and the Chaddock Bar, a number of such open lagoons can be traced. Long Bar is a flat ledge which once may have formed the barrier of a narrow lagoon open at its two extremities.

The so called reef off the south shore I look upon as a series of ledges, the remnants of the cliffs of the shore when it formerly extended to the present position (Plates XXI., XXIII.) of the reef. One cannot fail to read the mode of formation of this reef on seeing the work of destruction which has been and is still going on all along that coast (Plate XIX.). The shore of the island is gradually being eaten away at all the low points leading either into sinks like those of Sinky or of Hungry Bay, or into more elongated sinks like those which will be formed when the ponds lying close to the shore to the westward of Tuckerstown are invaded by the sea (Plate XIV.). The next process is the formation of a line of islands, such as still protect Castle Harbor and St. George Harbor on their sea face (Plate XXI.), or, as is well seen at Sinky Bay, where the line of rocks to the north and south of the opening is still connected with the shore line by a beach or neck, but which will soon disappear and change that bay and the one to the north of it into an extension of Whale Bay. On the sea face of that part of the coast extends a long line of isolated rocks, islets, rocky patches, and sunken ledges, which plainly tell of their former connection in a continuous ridge. Parts of these ledges are worn to the water's edge, forming flat ledges or mushroom-shaped rocks overgrown with Algæ and Serpulæ, and likewise the Serpulæ atolls (Plates XXIV.–XXVI.) and boilers of the shore line, similar to those which form the outer reef, and are separated by a belt of water varying from one and a half to four fathoms close to the lee side of the reef. At some points of the shore it is difficult to separate the line of the outer reef, and of its ledges extending towards the shore, from the ledges which form the Serpulæ reefs of the shore line itself (Plate XXVI.).

The amount of material which is kept in constant movement by the action of the sea within the outer line of ledges is very great, and is constantly increased by the additional material derived from the breaking up of the outer ledges by seas of unusual violence. The outer as well as the inner ledges become disconnected; passages between them are opened with four fathoms of water, or even more. The outer slope of the ledges is greater than the inner slope, the depth of water increasing in some places rapidly from the ledges which are awash at low water to six or seven fathoms, or even up to twelve off Castle Harbor. From that depth, judging from the soundings on the hydrographic charts, the slope is quite gradual, twelve fathoms usually being found at a distance of nearly a mile from the outer ledges; off the outer side of the western reefs the slope is somewhat steeper, and off the northeastern face of the reefs from the Western Blue Cut to North Rock the slope is slightly flatter.

Two small disconnected banks exist to the southwest of the Bermudas with a least depth, the one of twenty-one, the other of twenty-four fathoms (Plate II.). A depth of over 1,000 fathoms has been sounded between the main Bank and the Challenger Bank, while one of 580 fathoms has been obtained in the channel between it and the Argus Bank. The bottom in these is stated to be coral sand, and these banks may, like the Bermuda Bank itself, be the summits of volcanic peaks which have risen from a greatest depth of more than 2,000 fathoms at a distance of about nine miles from the 100 fathom line.

The Bermudas present quite a different physiognomy from that of the Bahamas. The hills are more diversified in shape, many of them quite conical, surrounding lowlands or sinks of considerable extent and of great variety of shape. Along the northern shore of St. George Island, except towards the east end, the hills are undermined as they reach the water line, forming low cliffs in marked contrast to those of the south shore, or on the waters of Harrington Sound and St. George Harbor and the northern coast of Castle Harbor, where in certain places the water has undermined the cliffs, and from them have dropped off huge masses leaving vertical sides of considerable height, from fifty to seventy feet. On the north shore only a few short stretches of the coast are occupied by sand beaches. Shelly Beach is the only one of considerable length. On the south shore we find sand dunes and many long stretches of broad sand beaches (Plate XI.) which supply the material for the dunes that are still in some places forcing their way inland over the ancient dunes, as at Tuckerstown, Elbow Beach (Plate XII.), and Whale Beach.

Professor Heilprin is of the opinion that perhaps the natural arches at Tuckerstown were formed at a time when the relations of land and water were different from what they are now; though it is difficult to ascertain precisely what his views are. Here, as at the Bahamas, many sinks occur in which, owing to the porosity of the rock, but little water can remain; if the sinks are at some height above the sea level, this undoubtedly permeates the interior of the island, and whenever the sinks reach below the level of the sea they are filled with brackish water. There is very little difference in the appearance of the rocks composing the islands. We have by no means the variety in the appearance of the æolian rocks met with in different islands of the Bahamas.

Solution has undoubtedly played some part in producing many of the fantastic spires of æolian rocks one meets in the Bahamas and Bermudas. The undermining of the shore cliffs, the mushroom shape of many of the isolated rocks and shore ledges, both above and below low-water mark, is in part due to the solvent action of sea water. This is especially well seen in the Bahamas on every island or islet at many of the channels leading from the sea face on to the bank.[1] On the Bermudas this is perhaps best seen in the formation of the pinnacles in the comparatively quiet waters of Mullet Bay and of Castle Harbor, and in the undermining of all the shore cliffs and the cavernous and honeycombed condition of the older ledge patches between the islands and the reef flats and those of the ledge flats themselves. Close to the Causeway at the northwest part of Castle Harbor there is quite a patch of low pinnacles from two to two and a half feet in height, which seem to show an active solvent action by the sea.

But the solvent action of the salt water cannot be compared in efficiency with the destructive mechanical action of the sea; the latter has to a great extent been arrested by the covering coat of Gorgonians, Millepores, Algæ, and Corallines, as well as of the more massive corals found thriving upon the heads, patches, ledges, and ledge flats of the inner and outer waters of the Bermudas. But these heads, ledges, etc. do not, as has been stated by former observers, owe their existence and their gradual increase to the corals, as they consist of æolian rock with only a protecting veneer of corals over their surface, constituting a coral growth, and not a coral reef.

In the region of the Everglades of Florida,[2] the process of solution of

[1] See A. Agassiz, The Bahamas, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, 1894, p. 49.

[2] The Topography of Florida, by N. S. Shaler, Bull. Mus. Comp. Zoöl., Vol. XVI.

the limestone rocks has been an important factor in shaping the general plane of the region. No one can find their way any distance into the Everglades without being struck with the deeply corroded and honeycombed aspect of the rocks, and the numerous sink-holes, due to the effect of the rain water saturated with acids derived from the decaying vegetable matter.

Heilprin has well shown that the lagoons and sounds of the Bermudas are not kept open through solution, and do not owe their origin or increase to that cause.[1] But I think he has underestimated the effect of solution on the cliffs and ledges where exposed to the action of the sea. The solution effected by the percolation of fresh water is clearly seen in the sinks,[2] pot-holes, and caverns opening out on all the cliff exposures and in many of the cuts in the honeycombed surfaces of the æolian rocks wherever laid bare. There is hardly a vertical wall or cut for a road which does not show some trace of the solvent action of water percolating through the æolian beds and covering patches of the edges of the strata with a stalagmitic coating, so as to obliterate their dividing lines or form small stalactites from bed to bed.

A comparison of the base of the sea faces of the cliff ledges with the sides of the mushroom-shaped rocks below low-water mark will clearly indicate the different kind of work accomplished by solution by sea water acting upon the more or less submerged vertical faces, and that exhibited by the action of fresh water some yards above the high-water mark. The effect of the solvent action of the sea water is readily traced above the high-water mark as far as the waves or spray can reach, and the encroachment of the sea water upon the area partly honeycombed by fresh water is most instructive (Plates XXVIII., XXX.). Above high-water mark the area exposed to this action is very considerable, and by the solvent effects of sea water upon the limestone area exposed be-

No. 7, 1890, p. 145. See also Murray and Irvine on Coral Reefs and other Carbonate of Lime Formations in Modern Seas, Proc. R. Geog. Soc. Edinb., 1889–90, Vol. XVII. p. 79.

[1] Bermudas, p. 44.

[2] Professor Dolley accounts for the formation of banana holes by the action of decaying vegetation collected in the holes, kept moist by the action of rains undergoing fermentative changes by the product of which the soft calcareous rock is dissolved and leaches away. This process undoubtedly acts as suggested by Professor Dolley, but only to a limited extent, as the most active honeycombing takes place on the surface of barren islands, where the vegetation has long ago disappeared, but where the surface is exposed to the combined action of rain and of salt water spray, as at Glass Window, Great Isaac, and other places in the Bahamas. See A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, 1894, pp. 30, 60.

tween high and low water mark a very considerable amount of lime must be removed, probably as much as the sea water will hold in a saturated solution. Additional lime may also be taken in solution, while innumerable minute particles are held in suspension during rough weather. At the time of our visit, the wind having blown for two days quite persistently from the northwest, the whole bank was fairly milky white in a belt extending from five hundred to seven hundred feet from the north shore. The isolated patches on the edges of the greater ledge flats were also indicated by the white waters surrounding them, while the deeper parts of the outer sounds were indistinctly indicated by a more bluish tint of the water.

The so called patches and reefs appear like diminutive vertical cliffs, or parts of cliffs, which once were broken off from the larger shore line cliffs then existing. Of course their faces and surface have been to a certain extent modified by the growth of corals upon them, but that only to a very limited degree. The coral patches are built up over a substratum of æolian rocks.

The islands as seen from the north present in general the features of the æolian hills of the Bahamas, although they have a more varied outline (Plate IV.). There are more conical hills, and there are not as many of the distinctive lines of ranges of æolian hills trending in one direction. Many of the islands in Hamilton Harbor are quite bare, their surface indurated by the action of rain and more or less honeycombed, as is the case in the majority of the Bahamas. The absence of vegetation is also marked over a great part of the western extremity of Spanish Point. There is a very fine æolian cliff on the bay at the foot of Admiralty House (Plate XVI.).

On the north shore the trees and shrubs of the main island do not run close to the water's edge. From the somewhat scantier groves of juniper crowning the summits of the successive æolian hills run broad grassy undulating slopes, terminating in the comparatively low vertical cliffs which characterize the north shore of the principal island. All the way from Spanish Point to Harrington Sound there is an unbroken line of these low vertical cliffs (Plate XXVIII.), with the exception of a few insignificant sandy beaches breaking in occasionally, the only prominent exception being Shelly Beach. The islands of St. George and St. David are comparatively bare (Plate V.), and the general aspect of the country at the eastern extremity of Bermuda reminds one of the aspect of the long lines of barren islands so common in the Bahamas. On the southern and western slopes of St. David junipers grow more abundantly, and the narrow band separating Castle Harbor from Harrington Sound is comparatively well wooded (Plate VI.). Though there has been over that district a greater denudation, judging from the general appearance of the outcrops of isolated patches of weathered æolian rocks, which form here and there low vertical cliffs.

The hills to the eastward of the flats extending on the north shore to St. George Island and the islands protecting the entrance of the harbor are comparatively bare of vegetation. The few stunted cedars and other bushes growing on the north side of that part of the Bermudas are mainly limited to the southern slopes. In fact, all the eastern part of the Bermudas, including the territory around Harrington Sound, shows far more than the central part of the principal island the effect of denudation which has taken place both there and in the western district of the group. The æolian rocks crop out in all directions, greatly weathered, and are near the surface changed to hard ringing limestone.

Toward the summits of the hills and in the saddles passing into the interior of the main island the cedars are more abundant, and in the lower and better watered valleys palmettos grow in small groves, forming the same contrast with the Bermuda cedars which they do in similar localities with the pines in the Bahamas. In all directions the wild verbena is to be found, either as the only growth in the more barren districts, or encroaching to a great extent on the open spaces of the wooded parts of the islands. In the valleys and lowlands of the islands, the soil is sometimes of considerable thickness. This is especially the case in the series of longitudinal sinks parallel with the south shore, which extend from Hungry Bay through the greater part of Devon.

At the western as at the eastern extremity of the islands we find a similar diminution in the vegetation. The southwest end of Somerset Island is bare, and the surface greatly worn. On the rest of the island there are fewer junipers than on the main island, and they are smaller and more scattered, as they are on the east end of the main island all the way from Wreck Point to High Point.

The difference in the aspect of the Bermudas and Bahamas is perhaps due to the prevalence of the trade winds in the latter, where they have had the tendency to build sand dunes bearing in one direction, their sea slope being abrupt, while the bank slope is more gentle, thus forming long lines of dunes lapping and running in one direction. This leaves long, narrow valleys between the ranges of dunes, and, as is well seen at Nassau and Andros, produces a greater monotony in the outlines of the islands as compared with the varied landscape of Bermuda. These valleys often become sinks (Plate XIV.) or elongated pools, and when broken into by the sea soon leave a line of cays parallel to the main shore. The winds are more variable at Bermuda, the islands being several degrees north of the limits of the trades, while the Bahamas are on their northern edge.

The general aspect of the Bermuda vegetation is characterized by the presence of the Bermuda juniper, which has assumed in these islands the prominence which the pine has taken on the Little Bahama Bank, on Andros, and on New Providence. Comparatively few of the plants so characteristic of the shores of the most barren of the Bahamas are met with near the shore line.

The Algæ and Corallines which I collected at the Bermudas were kindly examined for me by Professor Farlow. Off the sand beaches of the south shore on the bottom of the interior sounds the calcareous Algæ consisted mainly of species of Penicillus, of Bostricha, of Udotea, and of Halimeda, identical with West Indian types. On the rims of the serpuline atolls (Plates XXIV.–XXVI.) were collected species of Turbinaria, Galaxaura, Blodgettia, Dasyclades, Codium, Laurencia, Dyctyota, Eucheuma, Sargassum, Zonaria, Caulerpa, and Janca, all of which also occur on the outer ledge of flats and inner patches.

Professor Moseley collected a number of marine plants at the Bermudas which have been described in the Journal of the Linnæan Society, and his collections of the flowering plants formed the basis of the extended Report on the Botany of the Bermudas by Hemsley,[1] where a full account of the earlier sketches of the flora of these islands will be found. Professor Charles S. Dolley has also given an account of the Botany of the Bahamas.[2]

The principal accounts we have of the geology of the Bermudas are those of Captain Nelson.[3] The geology in Jones's "Naturalist in the Bermudas" (1859) is taken mainly from Nelson's Report. Rein gave a most interesting sketch of the geology of the islands in the Bericht. ü. d. Senckenbergische Naturf. Gesellschaft for 1870, page 140; he was followed by Sir Wyville Thomson,[4] who spent a short time in the Bermudas, and next in order came the visits of Rice,[5] of Fewkes,[6] and of Heilprin.[7] Darwin is of the opinion that the Bermudas "have a close general re-

[1] Voyage of H. M. S. "Challenger," Botany, Part I., W. H. Hemsley, 1884.

[2] Proc. Phila. Acad. Nat. Sciences, 1889, p. 130.

[3] Trans. Geol. Soc. of London, V. 103, 1837.

[4] The Atlantic, I. 289, 1877.

[5] Bull. U. S. Nat. Museum, No. 25, 1884.

[6] Proc. Bost. Soc. Nat. Hist., 1888.

[7] The Bermuda Islands, 1889.

semblance to an atoll," although they differ from one in several respects which he enumerates. Dana and Sir Wyville Thomson regard the Bermudas as part of an atoll. Thomson thought the islands were formed "by the raising of the weather edge of the reef above the level of the sea." [1] Professor Rice also considered it an atoll, but he was careful to distinguish between the present outlines and those which belonged to the original atoll.

Professor Rice suggests the following heads as his explanation of the geological history of the Bermudas: —

"1. A subsidence in which the original nucleus of the island disappeared beneath the sea, the characteristic atoll form was produced, and the now elevated beach rock was deposited.

"2. An elevation in which the great lagoon and the various minor lagoons were converted into dry land, and the vast accumulations of wind-blown sand were formed which now constitute the most striking peculiarity of the islands.

"3. A subsidence in which the soft drift rock around the shores suffered extensive marine erosion and the shore platform and cliffs already described were formed."

As regards 1. This is the natural explanation which would be given by the Darwinian theory of the formation of coral reefs to account both for the disappearance of the original nucleus and for the formation of an atoll. To those who do not accept the theory the disappearance of the nucleus is of course explained by subsidence also, but by the subsidence which followed the formation of the dunes from an extensive ring-shaped coral sand beach of which the material was derived from a reef growing upon the upper plateau of the Bermudian mountain, from a depth of less than twenty fathoms.

2. Whenever the accumulations from the reef were sufficient to build up a beach reaching the surface, all the conditions necessary for the formation of sand dunes existed, and we need not call upon either a subsidence or an elevation to account for the existing condition of the Bermudas.

3. The subsidence which I imagine to have taken place after the building of the dunes from the broad beach surrounding the original nucleus — now sunk or disintegrated — is, it seems to me, quite sufficient to explain the existing condition of the dunes and cliffs of the Bermudas, if the interpretation I have given of the base rock is the correct one.

[1] The Atlantic, I. 302.

I shall have occasion to refer to the views of Heilprin in the course of the following pages. Regarding the statement he makes on the nature of the Dolomitic reefs of the Tyrol, I would refer the reader to my Report on the Bahamas, page 179, where I have given an abstract of the views of the latest researches on the nature of the dolomitic reefs, views which are diametrically opposed to those advocated by him.

Heilprin says: "If it ever existed (the atoll condition), it has been completely masked by overgrowth; . . . the facts, such as they are, show with sufficient clearness that the present islands and reefs have little or nothing in common, beyond occupying position, with a pre-existent ring."[1] Yet it is on observations gathered in a district thus characterized by him that Heilprin bases his assent to the Darwinian theory of coral reefs, and he dissents from those who hold opposite views with a vehemence which might be excused in one having an extended acquaintance with coral reefs.

ÆOLIAN HILLS AND DUNES.

Captain Nelson was the first to call attention to the æolian character of the rocks of the Bahamas and Bermudas. This character *saute aux yeux* in every direction. In the Bahamas the vertical cliffs of the weather side of the islands show this to perfection, and here and there a quarry or a cut leaves no doubt that the substructure as well as the superstructure of the island is all of the same character. On the Bermudas one comes upon quarries of all sizes at all points, close to the sea level or near the highest summits, and at all possible intermediate elevations. The rock everywhere presents the same structure. There are also endless rock cuts for the passage of roads (Plate IX.), giving excellent exposures of the æolian strata twisted and turned in every possible irregular manner according to the direction of the then prevailing winds, or we may come across a patch exposed in a cliff or in a deep cut where the strata run parallel for quite a distance. As in the Bahamas, the surface of these æolian rocks has become indurated by the percolation of fresh water through its mass, and has formed here and there the thin ringing coating so common all over those islands, where the surface is not so well protected by vegetation as it is in the Bermudas. Throughout the islands we come upon evidence of the extensive denudation and erosion which have affected the æolian rocks of the islands and

[1] Bermuda Islands, p. 40.

worn them into the varied forms they have assumed, either along the more exposed shores or in the sheltered bays and inlets and sounds. Some of the æolian pinnacles off Castle Harbor have assumed the most fantastic shapes, due to the combined action of the weather and of the solvent and wearing action of the sea and rain.

Sir Wyville Thomson[1] has also given an excellent account of the general characteristics of the æolian formation. Heilprin has called attention to the comparatively insignificant part which corals play in the supply of the material which has gone to form the æolian hills of the Bermudas, and which, as in the Bahamas, is made up of many other organisms. Among them Nullipores, Corallines, broken shells, and Millepores take a most important place. In some localities, where the æolian rocks have not become well indurated, it is not infrequent to have secondary dunes formed from the sand derived from the breaking down of one of the softer cliffs, the dunes covering to a certain extent the older æolian hills, much as the æolian sand of the south coast climbs over the faces of the older hills.

The fine coral sand, which is so often spoken of as washed up on the shores by the sea,[2] is not, strictly speaking, coral sand, but is primarily composed of fine sand derived from decomposed æolian rock. This material is derived from the disintegration of the shore cliff ledges, and from that pounded off by the sea from the outer reef ledges, together with the broken shells of the mollusks living upon the flats and the small amount of material supplied by the breaking up of the massive corals and Gorgonians forming the coral growth upon the ledges, the ledges themselves consisting of æolian rock covered by Algæ, Corallines, Serpulæ, and Millepores. On the south shore this fine sand is blown far inland, forming dunes which cover extensive tracts;[3] at Middleton Bay beach they run up over the surfaces of the older solidified dunes, and reach to a height of over one hundred feet from high-water mark, encroaching upon the vegetation near the lee summit of the saddle through which they are blown. A row of small dunes has formed on the edge of the beach south of Whale Bay; a larger dune has also been piled up inland within the line of the beach dunes, extending over an older but smaller solidified dune (æolian hill); just as the beach sands at Elbow Beach (Plates XI., XII.) have run to a height of more than one hundred feet, although here the sand dunes do not extend as far inland.

[1] Voyage of H. M. S. "Challenger," The Atlantic, I. 310.

[2] Ibid., I. 307.

[3] See the excellent accounts of the dunes by Thomson, Ibid., 312.

It is probable that the other non-calcareous rocks and minerals which have occasionally been found may have been brought here by floating trunks and roots of trees, as is the case in many of the oceanic islands. We should, however, not forget the possibility of their being the fragments of the volcanic summit around which the proto-Bermudian reef was first formed, a summit which has completely disappeared, either owing to subsidence or to disintegration, or to both combined. There exists in the collection in the Government Building a piece of fine-grained æolian rock of a reddish tint from the north shore near Warwick Road, in which is embedded an angular fragment of basalt, or some eruptive rock.

For a coral island the elevation of the Bermudas is very considerable. The highest points are Sears Hill, 260 feet, Gibbs Hill, 240 feet, and Prospect Hill, 222 feet; a number of points reach an elevation of nearly 150 feet. On the Bahamas, with the exception of the highest points of Cat Island, which are said to reach 400 feet, the greater number of the æolian hills do not rise to more than from 60 to 100 feet, very many of the islands attaining a height of not more than from 20 to 40 feet, and only a few summits reaching over 200 feet. But it should be remembered that the heights named are not due to the elevation of coral reef rock, but to the height attained by the æolian hills which constitute the dry land of the two groups.

The Bermudas and Bahamas[1] offer an example of the thickness that a recent limestone deposit may attain during a period of rest. Assuming for the Bermudas a probable subsidence of 70 feet and a greatest elevation of 260 feet, we get an æolian coral limestone of 330 feet in thickness, the material of which has all come from a reef which itself was probably not thicker than 120 feet, or a total thickness of 450 feet. When we remember how readily these coral limestones are changed into hard ringing rocks, we introduce a new element into the discussion of the mode of formation of huge masses of limestone, especially in the region of the trade winds.

The beach rock and the so called base rock which have been observed at the Bermudas belong, I believe, to two different types. The former, the beach rock, consisting of coral or other sand, is deposited in strata dipping to the sea at a slight inclination, and is characteristic of all coral reef districts where sand is accumulated along a shelving line of coast. This frequently becomes hardened and changed to a ringing limestone, and is composed usually of rather coarse particles, but not

[1] A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, p. 183.

necessarily so. The base rock, considered by some of the writers on the Bermudas to underlie the æolian hills, I look upon as the modified part of the lower portion of the æolian strata changed into a hard ringing limestone in which all traces of stratification have often disappeared (Plates XVI.–XVIII.).

Heilprin argues that the beach rock has been elevated and is still found at an elevation of 12 to 16 feet; that it "antedates the last subsidence, . . . is at least as ancient as the lagoons and sounds, and probably much more ancient. Indeed, there is nothing that could lead one to suppose that it is not the original rock which was formed when the island first came to the surface. Although now exposed on the sea border, it is really an interior rock, as is proved by the broad band of land which must have been removed from the seaward side of the existing cliffs."[1] But this neither indicates elevation, nor that it is an original beach rock, since at the western extremity of the Bermudas, at Ireland Island, it is underlaid by true æolian beds fifty feet below low-water mark. It does not seem to me that beach rock is found at any greater elevation than that at which it could have been thrown up (and subsequently cemented) during a hurricane or violent gale.

The shore platform of which Professor Rice speaks appears to consist only of modified æolian strata, changed into hard ringing rock by the action of the sea, and of a shore platform eroded to ledges, as he himself describes them. He well says, when speaking of the relation between drift and beach rock on the south shore, "If we conceive the seaward face of the dune to be restored, it would certainly in some localities extend beyond the narrow shore platform into the area now covered by the sea."

Can we not find a simpler explanation of the formation of the Bermudas than the one suggested by Rice? Instead of a subsidence during which the nucleus disappears, followed by an elevation during which the æolian hills were formed, and then by a subsidence during which the present soft drift rock was eroded, as is suggested by Rice, we need only a single subsidence to explain all the phenomena, if, as I have suggested, base rock is only modified æolian rock, and beach rock has been forming continuously, and the æolian hills were formed at the time when the atoll was one gigantic annular beach constantly receiving fresh material from the outlying reef. This primordial reef has disappeared, and its remnants exist perhaps at depths of from twenty fathoms or more near the edge of the bank.

[1] Bermudas, p. 43.

Darwin's suggestion that the fringing reef on the south side of the Bermudas is evidence of recent elevation, does not, in view of the fact that the reef is made up of æolian ledges, need any discussion. Nor is the reason given by Dana regarding the cause of the great difference in the amount of dry land on the north and south side of the atoll a satisfactory one, if the ledges are æolian ledges, which were the first to disappear after subsidence began. I am inclined to look upon the present state of things as due to the former existence of lower æolian hills on the northern edge of the islands;[1] but his views would apply for proto-Bermudian times.

My observations lead me to look upon the beach rock of the Bermudas as consisting mainly of the larger and heavier æolian materials, which either have not been carried so far or blown to so great a height as the lighter æolian sand. The effect of the intermittent submersion of the æolian rocks exposed at low-water mark seems to be to cement the particles on the exposed lines of the knife-edged strata by a process very similar to that going on in all the deep road cuts on the islands. By it all traces of stratification are gradually lost, and an upper crust running over the exposed surface is formed irrespective of the æolian layers. Thus a belt of comparatively hard rock is formed, covered with a crust ringing to the hammer, which at first sight appears to be unconformable with the æolian strata. A closer examination invariably reveals at no great distance traces of the continuation of the æolian stratification, which continue plainly visible to high-water mark, to points below it, and at intermediate heights. Where the sea breaks violently against a vertical cliff, this cementing effect, accompanied by the disappearance of the evidence of stratification, can be traced in some cases well above high-water mark, where it gradually passes into the region honeycombed and pitted by the action of the rains. Such parts of the rocks cannot be distinguished from the base rock, and they have all its characteristics except that the cementation is not quite so complete (Plates XV.–XVII. and XXVIII.).

Here and there along the beaches beach rock is forming, as in some parts of Great Turtle Bay, of the shore south of Whale Bay, in Whale Bay itself, and between short projecting headlands where the *débris* from the outer and inner ledges accumulates in greater quantity. This beach

[1] It seems somewhat hazardous to attempt, as Rice has done, to correlate the movements of elevation and subsidence of what probably is a volcanic cone — of which he has, as he thinks, found evidence — with those of the American continent. (Bull. Nat. Mus., No. 25, p. 18.)

rock is generally readily recognized as such. It is formed in fairly thick layers, from two to six inches, and always dips toward the sea at a very moderate angle, and has nothing in common with the æolian strata against which it abuts. Parts of it may be ground up again by a storm should the calm between heavy surfs not continue sufficiently long for it thoroughly to consolidate.

All along the south shore one can find patches of beach rock dipping, as observed by Professor Rice, to the sea at a slight angle, — the modern beach rock of to-day, formed from the remodelling of the material thrown up from the outer ledges. This beach rock is formed similarly to that of the Florida Reef, where it plays so important a part in its economy, while at the Bermudas it is of comparative insignificance. It is often difficult to separate the beach rock from the base rock, but if, as I believe, what is called "base rock" is only modified æolian rock, the latter has not the importance attributed to it by Professors Rice and Heilprin. On White Cliff Bay there are some æolian cliffs dipping at a sharp angle into the sea, showing remarkably well the transformation of the thin æolian layers into massive compact beds of base rock, in which the dip of the strata can scarcely be detected, obliterated as it has been by the cementing and solvent action of the sea water acting upon them.

At Hungry Bay, Middleton Bay, and many points on the south shore, and on the north shore at Ireland Island, and on the north shore of St. George, there are numerous localities where it is possible to observe the transition of the inclined or horizontal æolian strata above high-water mark to the solid ringing limestone characteristic of the "base rock." On the shore of Godet Deep to the west of Heron Bay, at the foot of Gibbs Hill, the "base rock," can be seen passing gradually from the æolian beds into the solidified ringing limestone characteristic of the intratidal limits. The action of the sea cements the strata together, so that all trace of their æolian structure is lost. In many cases, however, we can trace the continuation of the æolian stratification indistinctly, so that I am inclined to consider what is termed "base rock" as due merely to such cementing action of the sea; the more so, as similar phenomena are clearly observable all along the Cuban coast on the shore edge of the elevated reefs between low and high water mark, where there is no question of an underlying base rock.

Professors Rice and Heilprin both speak of the "base rock" as distinguishing the old beach formation, and as indicating the position of the former sea border. It seems to me that this basal rock is æolian rock which has become excessively indurated by the action of the sea water upon the lower part of the æolian strata, and from being friable and crumbling, as they are above the reach of the sea, have been changed into a solid compact limestone, which rings under the hammer and can be chipped off in sharp-edged flakes. This is similar to the hard ringing beach rock now forming, and does not, it seems to me, indicate the position of the former sea border. Almost anywhere on the south shore one finds the base of æolian cliffs consisting of strata dipping inward, changed as high up as the sea can reach, into this hard compact ringing limestone. A similar "base rock" fringes all the Bahama Islands; inland at Nassau, as at the Bermudas, a few steps from the shore inside of the "base rock," the æolian structure is clearly defined in quarries and wells extending below the water line, but the sea, acting merely by percolation, has not changed their thin edges and cemented them as it has on the sea face of the shores where the strata are fully exposed to the action of the sea, and are in addition exposed for a longer or shorter time to the atmosphere during low-water periods or during the intervals between consecutive breakers.

Rice says of the locally called base rock, "that it does not uniformly underlie the softer rocks, nor is there any evidence that it is older than they."[1] A part of the confusion between base and beach rock seems to me to have arisen from considering the ledges of æolian rock as reef rock, and from the fact that there are a few localities on the south shore where beach rock is actually forming from æolian rock sand, derived from ledges in deeper water, mixed with broken shells and fragments of corals and Millepores. all of which particles are cemented by the deposition of lime held in solution in the water percolating through its masses.

Rice further says, "That there can be no absolute distinction between beach rock and drift rock will be manifest from the consideration that the two formations are in their origin strictly continuous." Yes, but their origin is not the same; the beach rock of to-day is formed in great part of the æolian rock of former days. I would go one step further in believing that the base rock is by no means usually beach rock, but that beach rock is a very local phenomenon, and is younger than the æolian rock, and belongs to the present epoch, and has been forming at different levels, as it is forming to-day in favorable localities, from the time the islands began to subside, as well as before that time. I am at a loss to know what Rice and Nelson can mean by reef rock, unless it be the thin crust of coral growth upon the ledges. I am inclined to adopt

[1] Bull. Nat. Mus., No. 25, p. 9.

Thomson's view,[1] that the Bermuda limestone is entirely æolian, and that the base rock does not underlie the softer æolian rock,[2] but to modify it by the above statement regarding the formation of base rock and of beach rock as now forming mainly from the remodelling of older material.

Rice accepts the Agers Island strata as beach rock, as well as the stratum at the south end of Ireland, a statement from which I must most emphatically differ. These beds contain marine shells in æolian strata. The base rock of the islands of Hamilton Harbor appears, as far as I have observed it, to be due to the induration of the lower strata of the æolian rock exposed to the action of the sea. There are but few islands in Hamilton Harbor of which the æolian strata do not dip at a considerable angle towards the low-water mark line into the sea. It is true that in some cases there are also æolian rock strata parallel with the sea, everywhere lying nearly, if not quite, horizontal, but these strata present the character of æolian rocks modified by the action of the sea.

On Grace Island, Hawkins Island, and off the Quarantine in Hamilton Harbor, we traced most distinctly, at low-water mark, æolian strata dipping at a high angle into the sea, and yet at many points they have passed into what is called base rock by the complete obliteration of the knife-edged strata from the abrading, the cementing, and the solvent action of the sea. The third island south of the Quarantine, Post Island, and Darrel Island all present the same phenomena of modification of the æolian rock into base rock. In the interior of a cavern leading into Quarantine Island we could trace the dip of the æolian rocks into the sea, and the same was the case at Hanson's Island. On the southwest side of Post Island the fine æolian lamination could still readily be detected below high-water mark through the "base rock" coating.

Nowhere in the Bermudas have I found corals above high-water mark or higher, the presence of which could not be accounted for by the action of high winds or waves during hurricanes, and surely the presence of caves above high-water mark is not in a limestone district an indication of elevation. If the explanation I have given of the formation of base rock is correct, its existence at a height of a few feet above high-water mark is not a proof of elevation.

[1] Thomson, Atlantic, I. 307.

[2] There was no "base rock" found while cutting through the æolian strata during the excavation of the Ireland Island Dry Dock.

FOSSILS.

On a small island to the south of Agers Island I found quite a number of species of marine shells identical with those now living embedded in nearly horizontal æolian strata a few feet above high-water mark. Also a bank of Chama evidently thrown up or blown up during a hurricane, much as we find Strombus on some parts of the Bahamas thrown up in great banks high above high-water mark. That marine shells should thus be thrown up or blown up to such considerable heights in what may, in proto-Bermudian time, have been a protected sound, as well as is Hamilton Harbor, is not extraordinary. We need only recall the great violence of the hurricanes which sweep past and over the Bermudas, during which vessels have dragged their anchors in the sheltered inner harbor of Hamilton, where the wind and sea have a comparatively limited range.

Below that, but in æolian strata, these fossils extend to low-water mark, apparently embedded in the "base rock." These lower strata have at first sight all the appearance of beach rock; they consist mainly of particles larger than æolian sand, which probably have not been blown a great distance upward from their base. But these strata, consisting of larger brecciated fragments, have, like other æolian beds, been changed into the hard ringing limestone so characteristic of nearly all the exposures below high-water mark.

During the very low tides which prevailed for the last days of my visit at the Bermudas, I was able to trace the existence of æolian beds underlying the fossiliferous beds with the base rock lying between them. The fossils are embedded in æolian rock, and in certain spaces, which have become cemented so as to destroy the laminations, they appear to be embedded in the base rock. The existence of these fossiliferous beds above high-water mark in the islands of Hamilton Harbor has led Rice to assume a period of slight elevation as having occurred in the Bermudas, and further to maintain that much of the interior of the islands is underlain by beach rock, a statement with which Professor Heilprin agrees in the main. The size of the material and the broken shells thrown up at Shelly Beach show how high up material similar to it may, even under ordinary circumstances, have been thrown up and become embodied into æolian beds without its being any indication of a period of elevation.

The fossiliferous strata of St. George Island,[1] mentioned by Professor Rice, seem to me to belong to the same category of rocks which crop out in Hamilton Harbor. They are æolian rocks containing many species of Lucina, Chama, and the like; and as all the marine shells near Agers Island must have found their way into these æolian strata under the action of the winds or the sea, the parts of the strata below high-water mark have here also been partly changed into the hard ringing limestone of the base rock. Professor Heilprin also found marine shells in æolian rocks.[2] In a hill to the eastward of Stone Hill I have found a few recent land shells in very friable æolian rock.

An interesting collection of rocks and sub-fossils from the æolian rock quarries and other localities is preserved in the Government Building. It contains among other specimens a small collection of casts of Tellinas and Lucinas obtained from a submarine cut in Tomlin's Narrows, sixteen feet below low-water mark. This would indicate the existence of a bay or sound, as in our day, at the time when the level of the sea was higher, before the land had by subsidence obtained its present level, and it is no indication of elevation any more than the presence of the living shells of to-day as fossils would indicate such a change. It also contains the shell of a tropic bird egg found in æolian rock quarries in the Middle Road in Devonshire, the bones of a snipe? obtained from æolian rock near St. George, and marine shells from a bed twenty feet above the sea and one hundred feet away from it, occurring in æolian rock on the main road from the north side of Gibbs Lighthouse Hill. There is also in the Government collection a large Turbo, which was found in a cutting in æolian rock at the east end of Hamilton; this Turbo is said to be extinct, but is found sub-fossil in the highest æolian hills.

[1] I would consider the peculiar conglomerate of Stocks Point as only the higher limit of a local beach rock, which may have been thrown up in a locality specially exposed to gales or hurricanes, and limited in extent. It contains fragments of the underlying drift rock, and resting upon it, as Rice observes, is the ordinary drift rock. But on both sides of the beach rock we find æolian drift rock reaching to the sea, which would indicate either a fault or that the conglomerate was older than the æolian hills of the Bermudas, neither of which suppositions is in accordance with other facts observed in the vicinity.

[2] "At several points, more particularly along the north shore, I found marine shells (Lucina, Tellina, etc.) embedded in unquestionable drift rock, and indeed it could hardly have been expected that such association should not occur. . . . The same is also true in a measure of the occurrence of land snails. . . . One of the commonest shells of the lower drift rock is the large *Turbo (Livona) pica*, a shell which appears to be very abundant about the coast." Heilprin, Bermudas, p. 35.

THE SOUNDS AND LAGOONS.

Plates II., IV., VI., VII., XIV., and XXVII.

The sounds are sinks and depressions filled with sea water, as was first suggested by Rein, and none of them are secondary atolls. They owe their origin either to the breaking through of low saddles dividing sinks from outer lagoons, or to subsidence, allowing the water of adjacent lagoons or the sea to flow in over separating ridges, or to both these causes.

Professor Heilprin gives an excellent description of the rapid waste which the islands are undergoing, and of the formation of the sounds, on pages 36 and 37 of his Bermudas.

The improbability of the sinking of the roofs of large cavernous areas to form the sounds, as has been suggested by Rein [1] and Fewkes,[2] does not militate against local disruptions on a limited scale, of which, as Heilprin states, there is abundant evidence.[3]

The lagoons of the south shore between Tuckerstown and Newton Bay are brackish pools separated by low hills from the sea (Plate XIV.). In many places it would require comparatively slight inroads of the sea, or but little subsidence, to change them into diminutive harbors or sounds, similar, but of course on a smaller scale, to Castle Harbor or Harrington Sound. The shore platforms of Harrington Sound and Castle Harbor are similar to the ledges which extend off the cliffs from the outer shores of the islands (Plates VI., XXVII.).

Harrington Sound seems to have been formed in exactly the same way as the smaller harbor indentations of the coast. Its shores present all the phenomena of disruption by waves exhibited by the outer shores, although in a less degree. The action of the sea is of course much less powerful, yet is sufficient to have undercut the cliffs, and in some places, as on the north shore of the sound, they are fully as high as many of the more striking cliffs formed on the sea faces outside by the splitting off of large slices of the æolian hills.

We find in Harrington Sound islands, islets, and many honeycombed ledges (Plate XXVII.), pinnacles, and mushroom-shaped rocks, due to

[1] Rein, Bericht., 1870.

[2] Fewkes, J. W., Proc. Bost. Soc. Nat. Hist., 1887, p. 518.

[3] Bermudas, p. 45.

erosion or to the solvent action of the sea, differing in no way from those made along the north and south shores of the islands. Along its shores there are numerous ledges running out from or parallel with them, extending between the small rocky promontories, which if cut off would form a series of patches close to shore similar to those which extend from the north shore inside of the banks towards the outer ledge flats and upon them. Gorgonians, corals, and other growths, have settled upon the ledges since the time when they and the saddles have sunk or have been eroded to their present level, giving the sea access into the interior of the various sounds so characteristic of the Bermudas. This is admirably shown by the cutting of the sea into St. George Harbor, so as to give access to it both from the outer and inner waters of the bank. These passages are narrow, so that corals do not get a sufficient supply of fresh water, and hence are far less common than on the shelves of Castle Harbor, which is freely connected with the sea on its southern exposure. In Harrington Sound the connection with the lagoon is still less open, a narrow cut on the north being the only opening through which the inner waters of the bank gain admission to it. Castle Harbor in the same way is connected freely with the sea on the south, and but slightly with the inner waters of the bank, through the same opening which connects them with St. George Harbor.

A narrow cut separates Somerset Island, which forms the western boundary of Great Sound, from the main island. This sweeps round to the eastward and forms the southern flank of Port Royal Bay, which is separated from Great Sound by the line of islands extending outward from Tucker to Darrel Island (Plate II.).

The depth of water in the sounds is very considerable, not only in the sounds themselves, but also in the inner waters of the reef, which have been called lagoons, but are hardly such in the sense in which that term is understood. It would greatly conduce to accuracy to call the inner basins of deep water — surrounded on one side by the outer ledges of the reef, and on the other either by the connecting patches of ledges or by the islands in part — sounds also, for such they undoubtedly are, and were sounds similar to those now existing and known as Great Sound, Port Royal Bay, Hamilton Bay, St. George Harbor, Castle Harbor, and Harrington Sound.

In Great Sound we find from ten to eleven fathoms. In Harrington Sound as much as twelve fathoms is found in several spots. In the outer sounds we do not as a general rule find so great depths. What we may call the Brackish Pond and Bailey Flats Sound has a general depth of only from five to six fathoms. The great sound known as Murray Anchorage, to the northeast of Bailey Bay Flats, is somewhat deeper, and varies from seven to nine fathoms. To the north and northwest of Murray Anchorage the water is still deeper, varying from seven to ten fathoms, with a deeper bight to the northeast of Three Hill Shoals, where the depth is twelve fathoms close to a spur of the East Ledge Flats. These depths all run close to the five fathom line, which may be called the inner edge of the outer flats or ledges extending from East Ledge to the Ledge Flats north of Blue Cut. On these the depths vary from one and a half to four fathoms, with occasional deep holes, with a white sandy bottom, or islets separated from the edges of the Ledge Flats or inlets running in from the sounds, and patches surrounded by from seven to ten fathoms. To the westward of Three Hill Shoal the clear bottom averages from seven to eight fathoms. In the sound between Brackish Pond Flats and Elies Flats the depth varies from six to ten fathoms, with occasionally a five fathom sounding between the numerous isolated patches of ledges inside of the five fathom line. The extensive sound to the west of Wreck Hill, extending to the Western Ledge Flats and southwest of Elies Flats, varies from seven to eleven fathoms (Plate II.).

In St. George Harbor the bottom is hard in five fathoms. The dredge brought up many specimens of Toxopneustes and Echinometra. We found only a few patches of Gorgonians and of massive corals in the harbor itself, while in Castle Harbor, which has a freer communication with the sea, the patches of corals on the ledges are quite numerous, having much the same characteristics as those of the Ledge Flats.

In Harrington Sound the growth of Gorgonians and massive corals is also less prominent than in Castle Harbor, and the development of Gorgonians. Algæ, corals, and corallines in these sounds, as well as in the sounds at the western end of the islands (Hamilton Harbor, Port Royal Bay, and Great Sound), seems clearly to indicate that as fast as they became connected with the outer sounds and in proportion to the accessibility of the sea, corals have gradually found their way into these sounds, and have also developed in proportion to it, being less abundant in sounds indifferently connected with the open sea. All the conditions of the coral growth indicate a comparatively recent inroad of the sea, first into Castle Harbor, next into St. George Harbor, and finally into Harrington Sound. The corals have found their way into the sounds much as the corals forming the veneer of the outer reefs have found their way from the West Indies in the track of the Gulf Stream, or perhaps have been derived from the corals forming the proto-Bermudian reefs, which in their turn were introduced from the West Indies through the same agency.

It seems probable that the cedars dredged up in the excavations for the channel in St. George Harbor were floated into the basin from the adjoining hillsides; but in the case of the red earth coming from the excavation in Ireland Island, the site of the present dockyard was probably a banana hole, which during the subsidence sank to its present level, say fifty feet or so below low-water mark.

The conditions of growth of the corals in the sounds of the Bermudas do not seem to me to have any bearing on the growth of corals in the lagoon of an atoll. The lagoon of an atoll swept by the currents, with its rim pounded upon by the surf, and the Bermudian Sound, with its comparatively quiet expanse of water formed under such different conditions, do not seem to have many features in common.

There are near Harrington Sound, between it and Castle Harbor, three small sounds in the process of formation, which present all the characteristics of the larger sounds, only on a most diminutive scale in proportion to the range of the sea they enclose. The two most interesting are one to the east of Harrington House, and one called Webb's Pond, on the road to St. George, after passing the Flats. The latter is an irregularly pear-shaped, miniature sound, about 200 by 180 feet, and perhaps 200 feet from the north shore. At its southern extremity there are low crumbling cliffs. The depth is said to be fourteen feet. Both of them are merely sinks close to the sea, but only connected with it under ground, and perhaps filled by percolation of the sea through the æolian rock. The tide rises and falls in both.

Spittle Pond, on the south shore, is a brackish sink surrounded by grassy shores, which barely reaches high water-mark. Between Tuckerstown and Newton Bay there are also a couple of brackish ponds, the shores of which are protected by mangroves.

While the sounds undoubtedly indicate subsidence, they are not lagoons surrounded by corals, such as we find in atolls, and should not be compared to them. They are sinks or low tracts, which have become connected with the outer waters into which corals have found their way. Such sinks we find ready to be changed to sounds or pseudo lagoons at many points of the Bermudas; as, for instance, along the South Shore road from about Walker Bay nearly to Hungry Bay, there are a series of low valleys about at the sea level, and separated from the sea by a ridge of low æolian hills. A further slight subsidence would change them into shallow harbors by the rushing in of the water over the lowest of the dividing saddles. A similar low tract extends to the south of Government House between it and Hamilton, with an outlet into Boss Bay.

DISTRIBUTION OF THE CORALS.

The Bermudas are the most northerly limit[1] where reef-building corals are known to occur, unless we can call coral districts areas where Astrangia, Primnoa, and other northern types, like Caryophyllia and Lophohelia, are to be found.

The absence of Madrepores, to which Thomson called attention, is very striking. There are thus wanting the very elements to supply the bulk of the material broken off and thrown up by the sea to accumulate as beaches or islets.

It is interesting to note that the littoral marine fauna of the Bermudas is the same as the shallow water fauna of the West Indies, and that its existence here is one of the finest examples of the effects of great oceanic currents in shaping the geographical distribution of animals the embryos of which are pelagic a sufficient length of time to be transported to this their northern limit from the Bahamas and other parts of the West Indies. During my stay at the Bermudas, every day when the wind blew from the southwest or west the common West Indian Physalia appeared in great numbers.

Besides marine animals, floating masses of wood coming from the West Indies are frequently stranded on the shores of the Bermudas, these sometimes carrying fragments of rocks. A large ellipsoidal mass of floating pumice, measuring eleven inches in length, was picked up off the south shore by the Hon. Archibald Alison. A similar float, thrown up on the south shore, is preserved in the Museum of the Government Building. This piece is filled with red earth.

[1] The minimum temperature of the surface of the sea occurs in January and February, when it varies between 59° and 63°. In March it varies from 62° to 66°. In April its maximum has already risen to 71°; in May the maximum is 76°, minimum 70°; in July the minimum is 79°, maximum 82½°; in August the maximum is 85°, minimum 82½°; in September the maximum is 83°, and the minimum 75°. The temperature then falls rapidly from 69° and 74° in October, down to 61° and 65° in December. The minima are remarkably low temperatures for a coral reef district. The above data were kindly furnished me by Mr. John C. Watlington, of Hamilton.

Wallace lays great stress upon the pumice thrown up from the sea as being a possible explanation of the source of red earth. Although I examined the beaches of the south shore many times, I never succeeded in finding a single piece of pumice. Red earth is abundant, both at the Bahamas and Bermudas, in localities to which drift pumice could not have access.

I was greatly struck with the apparent want of adaptation to their surroundings of the coloring of many of the Bermudian marine invertebrates. The dark violet Diadema and Echinometra are very common on the faces of the steep rocky patches, as well as in the sandy hollows of the surface of the bank. In the one case they are part of the brilliant patchwork forming the coloring of the reef surface; in the other, they stand out most prominently against the whitish Nullipores. Diadema in Florida, as well as in the Bahamas, is often found in colonies entirely filling the bottom of some sandy depression in the midst of a white field of surrounding coralline bottom, the patches of brilliantly colored corals and Gorgonians themselves standing out as a whole in striking contrast to the whitish bands of coralline or æolian sand separating them.

Professor Heilprin has greatly added to our knowledge of the fauna of the islands,[1] which was previously mainly derived from the sketch of their Natural History by Jones,[2] and has also given a list of the species of corals belonging to the islands.[3]

The low tides prevailing during the last days of my stay at the Bermudas enabled me to note the luxuriant growth of Millepores and Gorgonians on the surface of the many patches which were nearly awash during these days. The flats extending to the north of Ireland Island, and the flats to the southeast of the North Rock Ledge, were specially noteworthy for their abundant coral growths.

On passing through Mangrove Bay to reach Hogfish Cut from Great Sound, we dredged Oculinæ from the deepest part of the bay; the bottom in four fathoms is very fine sticky silt, almost marl. Corals in Hamilton Harbor, Great Sound, and Port Royal Bay are limited to a very scattered growth along the shores of the islands of these sounds below low-water mark. In the deeper parts of the sounds Oculinæ grow to considerable size. Zoanthidæ are abundant on the higher knolls of the outer reef, and also on the serpuline atoll-like structures. Porites is quite common on the outer reef. This is in marked contrast to the

[1] Bermudas, p. 97.

[2] The Naturalist in the Bermudas.

[3] Bermudas, p. 98.

abode of Porites in Florida, where it is usually most abundant on flats more or less sheltered.

The corals at the Bermudas as well as at the Bahamas do not generally reach the surface. They form a more or less connected belt of coral growth in from five to six fathoms on the inner edge of the flats to the outer limits, the beginning of the broken ground. the corals extending to eight or ten fathoms on the southern sea faces of the flats.

LEDGE FLATS AND PATCHES.

Plates II., XV., and XVII. to XXVI.

The ledge flats, patches, or coral heads, are names given to different parts of the reef, which has universally been considered to owe its existence to the growth of corals, and much of the confusion existing regarding the structure of both the Bahamas and Bermudas is due to the fact that corals have been assigned a part in the building up of these islands which they have never performed.

The flats consist, not of coral heads, though they are often so called both here and at the Bahamas, but of ledges of æolian rock rising from a depth of five to six fathoms or more (Plate XVIII.). These ledges, with their nearly vertical sides and their slopes deeply honeycombed, drop rather abruptly into the coralline bank bottom, which forms more or less extensive irregularly shaped patches separating the ledges. The surface and sides of the ledges are veneered by corals,[1] Gorgonians, and Millepores; the sharper edges of the ledges are covered by incrusting masses of Millepores, and calcareous and other Algæ grow in great profusion between the corals and Gorgonians. The Millepores, Gorgonians, Nullipores, and calcareous and other Algæ, are by far the most abundant growth on the inner patches. On these we find only comparatively few of the larger Mæandrinas and Astreas. The massive corals increase greatly in number as we approach the outer edge of the reef, and the finest and most numerous specimens appear to grow on the outer sea face in from five to seven fathoms of water. Beyond that, or even at lesser depths, in five to six fathoms, the broken ground begins. This consists mainly, as far as I could ascertain from the observations of others and gather from my own notes and dredgings, of Gorgonians,

[1] Thomson thinks that the patches have been built up by the corals. Atlantic, I. 304.

masses of Algæ and of coralline Algæ, and Nullipores, with comparatively few massive corals. As far as I am aware, this broken ground does not extend on the northern sea face of the ledges as far out as off the southern ledges, where the fishermen report its existence to a depth of from sixteen to seventeen fathoms.

The ledge patches rise in steps from the coralline bottom depths, much as they fall in successive ledges off the shore cliffs. As we approach the bank edge of the flats, the ledges become smaller, the depth of water increases, and the sand spaces between the patches increase, often forming long tongues extending into the main body of the ledges of the flats. Many of the ledges near the edge come quite close to the surface, and a great number are awash at low water, although the depth of water between them is greater than at the point we might call the crest of the ledges. The nearer we come to the breakers, the greater becomes the wear of the sea slopes of the ledges, so that in many places their slope is quite abrupt, from two or three to five fathoms, and a somewhat gentler slope extends from that point seaward to form the broken ground.

The high æolian cliffs of the south shore probably extended to the outlying reef, which is itself only a series of ledges running parallel to the coast, the crests of which are bare at low water. On these and the inner irregular flat ledges which dot the bottom over greater or smaller areas between the outer ledges and the shore grow corals and Gorgonians, — a comparatively thin veneer, which supplies, when dead or beaten off by the surf, a part of the material which goes to form the sandy beaches of the south shore, — though by far the greater mass of the material is derived from the disintegration of the ledges themselves. So that the submarine remnants of the ancient æolian hills supply the material which to-day creeps over their faces and finds its way inland, much as they in their own time must have crept over the lowland existing within the limits of the proto-Bermudian coral reef.

From the observations I have thus far made, it seems to me as if the corals now growing at the Bermudas had, as at the Bahamas, played a very unimportant part in building up the mass of the reefs. It is true that some of the flats are largely formed of coralline coral and æolian sand, derived in part from the coral patches which line their faces. But as yet no islands or islets have been formed by their disintegration, showing that the coral growth is not rapid; and although in some of the patches along the inner edges of the flats and on some of the connecting patches the corals have attained sufficient thickness to conceal the original ledges, and perhaps in many cases to build them up from a couple of fathoms or so to within the limits of low-water mark. Their growth can in no way be compared to the massive coral reef structures we find in the West Indies and Florida.

Off the north, as well as off the south shore, the patches nearest the land are merely ledges consisting of larger or smaller pieces which have become separated from the shore cliffs by the action of the sea, or else they are more extensive patches marking the position of small islands, islets, or rocks which were once more or less closely connected with the main island, and which now run as ledges parallel to the shore line. These ledges, if close to the shore, are barely covered by Algæ and a few barnacles, or Mytilus, or isolated corals, or such animals and plants as we find on the immediate shore line. Farther from the shore they become overgrown with a greater profusion of Algæ and Nullipores. As we proceed from the north shore to the ship channel, we gradually come upon ledges on which are found corals and Gorgonians, Algæ and Nullipores occurring as on the ledge flats, but in less profusion. It is on the outer ledge flats, which have probably been under water longest, that we find the most abundant growth of corals. While I do not deny that some of the ledges have been increased in height, and slightly in width, by the corals covering them, yet the corals have played but an insignificant part in building up the ledges themselves. The ledge flats are the remnants of the proto-Bermudian æolian land worn down by the action of the sea to a certain level, and upon these æolian ledges forming the underlying foundation of all the patches, the coral reefs — viz. corals, Corallines, Gorgonians, and Algæ — have grown, but only as a comparatively thin veneer upon the pre-existing æolian ledges.

The surface of many of the ledges outside of Hungry Bay on the south shore, exposed at low water, is covered with coral growth, especially the ledges on the inner face of the outer patches of the south shore reef. The ledges exposed at extreme low water are irregularly shaped, rising from two to four fathoms of water; they are greatly undercut and abraded, and show signs of the solvent action of the sea. The vertical and sloping faces of the ledges near shore are covered and protected from wear by a thick growth of Algæ and Corallines, similar to the growth which protects the upper face of the ledges. But on the upper surface there is in addition an abundant growth of Serpulæ. Between the outer ledges and the shore, more or less protected by the isolated outer patches extending to the reef, a sort of lagoon is formed. In this lagoon are found numerous ledges; then, closer to the shore, overgrown with Algæ, Corallines, and Serpulæ, there is deeper water, with corals and Gorgonians. Many of the ledges within the lagoon consist of the miniature serpuline atolls and reefs described in another section of this Report.

On the inside of the outer serpuline reef ledge, corals and Gorgonians flourish, according to the depth and the position of the ledges intervening between the outer reef and the shore. Off Sinky Bay the bottom outside of the outer reef ledges is hard. Off Castle Harbor, as far as the channel leading into St. George Harbor (Plate XXI.), we can readily trace the gradual formation of islands and islets originally constituting the continuous barrier to a sound formed by the breaking through of the lower saddles of the ridges dividing it from the sea. The outer row of these islets and islands differs from the inner one in having comparatively wide ledges, projecting round the base of a central pinnacle more or less undercut. As the central pinnacles are cut away, they leave only a narrow ridge on the broad platform, the ridge itself also disappears, and on the outer line of ledges have grown Algæ, Serpulæ, and other organisms, which prevent in some cases the further wearing away of the whole ledge, protecting its most exposed parts. The sea breaking upon the upper surface of the ledge soon forms the more or less regular serpuline atolls and "boilers" of the south shore which will be described later on. They are found on all the breakers on the outer side of the reef ledge flats, like Mills Breaker, the North Rock, and others; serpuline reefs extend off the headland on the west of Church Bay. The Southwest Breaker is the westernmost of the line of serpuline reefs skirting the south shores. It has three "boilers" on it, a long one and two smaller ones, with a small serpuline atoll to the southwest of the main ledge.

There are on the eastern part of Castle Harbor itself a number of ledges coming to within a foot or two of the low-water mark. They are covered with corals and Gorgonians, Algæ and Corallines. The Gorgonians are not very flourishing, but the Nullipores and Algæ grow in abundance between the massive corals. The patches are separated by a fine sandy bottom. On the outside of Castle Harbor there are many coral patches, boilers, and ledges extending outward of the outer ledge, to a depth of from seven to eight fathoms, with an occasional ledge rising from ten fathoms (Plate XXI.). But, as a rule, outside of the outer reef ledges we come upon the "broken ground."

The line of reefs to the south of the island extends unbroken from St. David Head to off High Point. The ledges are all æolian shore cliffs which have become separated from the island by the action of the sea, then beaten away, abraded and eaten into by the surf, and, according to their position, the depths in which they are found have been transformed into the peculiar agglomeration of reefs and ledges off the south shore. They form an incipient ledge flat, as it were, of which the outer line is still very prominent, and which the outer breakers have not as yet undermined and eaten away, so as to leave, as they do round the ledge flats, only a few isolated rocks cropping to the surface. Some of these ledges are a hundred and fifty feet in length, and even more, with a breadth exposed at low water varying from two or three feet to thirty or forty feet; others are only small pinnacles a few feet in diameter. All, however, present nearly vertical faces, and rise abruptly from two and a half to four fathoms. They are all more or less undercut, eaten away, of irregular mushroom shape, and the breaking up and disintegration of the exposed pinnacles after they have been so undermined as to break from their base supply a large amount of the material thrown up on the beaches.

A section along the slope of the sea beach of the south side of the island shows first a shore line of flats, ledges, and pinnacles, then a second or a third row of mushroom-shaped undercut rocks, some reaching to above low-water mark, others barely awash, or a few feet below. A few of the ledges may still be surmounted by æolian rock pinnacles, while the submerged surface of other flats is either protected by Algæ, Corallines, or Serpulæ, and according to their depth they are changing or have been changed into serpuline reefs. A few of the ledges in deeper water inside of the outer line of ledges are covered with corals and Gorgonians. The outer row of ledges forming the reef do not differ from the rows of rocky ledges inside of the reefs, or from those close to the shore. There are on the outer lines, however, no ledges surmounted by pinnacles, most of them having been changed into boilers, or into long ledges with winding or S-shaped vertical walls, the surface of which is protected by Algæ, Serpulæ, and other growths. Outside of the outer row of ledges we come upon the broken ground bottom, which consists of flat ledges extending from five to fifteen or more fathoms. Upon these in the shallower parts flourish the massive corals and Gorgonians, while over the deeper parts extend mainly the Gorgonians and Algæ, as well as Corallines. Such broken ground bottom occurs off Chaddock Bar, off Long and Little Bar, off the Chub Heads, and all the way from the Southwest Breaker outside of the south shore reef to off Castle Harbor and off St. David Head. Similar broken ground occurs wherever on the Admiralty Chart it is marked *r*, — off the Mills Breaker Channel, outside of the North Rock Channel, the Eastern and Western

Blue Cuts, and Chub Cut, as well as between Long Bar and the West End Ledge Flats. There are outside of the reefs many areas of rocky bottom, marked *r* on the chart, the remnants probably of extensive æolian ledges.

Nowhere do we find more fantastic shapes in the pinnacles remaining on some of the ledges than those which are seen to the south of Nonesuch Island, and extend to the eastward toward St. David Head. The islands pass into pinnacles, into ledges, and finally into boilers, in regular succession, and in proportion to the exposed condition of their position. Similarly eroded pinnacles are also seen on a smaller scale, but of fully as fantastic shapes, in St. George Harbor, in Mullet Bay, and on the south side of the causeway on the western side of Castle Harbor.

The patches outside of the reef off the south shore can be clearly seen extending a short distance to sea, separated by irregular white patches of sand. The inner ledges, forming the patches between the outer reef and the shore, are most capriciously distributed. Outside of the reef off the south shore the corals do not seem to thrive, and the broken ground is comparatively barren, though we find an occasional patch where Gorgonians, Algæ, and massive corals are more abundant. The coral growth is more that of the broken ground than of the reef flat ledges or of the connecting patches.

Heilprin has noted the great importance which the Millepores take in the composition of the bank sand bottom. On the south shore, where Serpulæ are so abundant, the fragments of their pinkish shining tubes can readily be distinguished in the coarser fragments of the sand thrown up on the many beaches along the shore. While in the Bahamas I was struck by the importance of the Millepores in the economy of the reefs. They seem to be far more abundant there than upon the Florida reefs, where the Madrepores take an extraordinary development, while they are absent in the Bermudas.

The south reef extends at a distance from the coast of about one thousand to fifteen hundred feet throughout its length from the entrance to St. George Harbor to the eastern side of Hogfish Cut. It has nothing to do with a barrier reef as such. It is a barrier ledge of æolian rocks derived from the old shore line, and not a barrier reef formed by corals, as Heilprin would lead us to suppose. The description which he gives of the work of destruction going on upon the barrier reef which skirts the southern coast is somewhat unfortunate, as the material of which he speaks as "blocks of coral and of coralline . . . detached and broken," is derived from the rehandling of the ledges of æolian rock of the former sea-shore. The corals now growing play an infinitesimal part in the forming of the sand dunes which "stand on the eminences which to-day are the Bermudas." His description would apply to the original reefs from which the Bermudian hills were formed, but is scarcely applicable to the work doing in our day.

Heilprin, after quoting Dana's description of the reef of an atoll, finds it largely applicable to the condition of the Bermudas, an opinion to which exception must be taken. From what has been said it will be seen that the Bermudian coral reefs have little if anything in common with the coral reefs of an atoll. Certainly no more erroneous statement could be made than that "the more seemingly favored patches are the creations of the surf themselves." The Bermudian reef corals are, like the Bahama reefs, submerged, rarely come to the surface, and have not supplied any considerable part of the material which has gone to build up an extent of land either in the Bahamas or the Bermudas. In the Bahamas the corals flourish most profusely in depths of from five to twelve fathoms; at the Bermudas six to seven is their limit, and those on the sea face of the ledges do not seem any more abundant than those on the edges of the flats. I was not able in the several sections I made across the sea faces of the southern reef to find the unbounded profusion of coral growth which Heilprin observed. In fact no one has better shown than he that the coral reefs which now encircle the Bermudas have had no share whatever in their formation, and I fail to see how the fact that subsidence has given to these islands their outline of to-day has any bearing upon the theory of the formation of coral atolls by subsidence. Any land surface exposed to the action of the inroads of the sea owing to its subsidence would have been eroded to some extent according to the nature of the rocks composing it. The subsequent formation of a thin veneer of coral reefs upon its sunken ledges would not have any bearing on the theory of the formation of thick masses of limestone by subsidence. It may be interesting, in this connection, to refer to Heilprin's statements "that the present form of the Bermuda Islands bears no relation to the ring of an atoll," and that "the existence of an atoll is not demonstrable."[1]

I fully concur in what he says regarding the subsidence which followed the elevation of the islands to their greatest height. Heilprin was impressed by the absence of loose boulders of rock (coral?).

[1] Bermudas, p. 46.

This is natural, for we find on the ledges of the Bermudas mainly æolian rock masses readily crumbling to pieces, a thin coral belt, and but little solid material to be shaped into boulders by the sea, and similar to that of reefs studded with massive corals and Madrepores, which are usually crowded with boring Annelids, Sponges, and Mollusks, and which thrive in such localities, but find nothing to feed upon in the æolian rocks forming the base of the ledges of the Bermudas, or in the æolian sand flats, the bottom of which is constantly kept in movement. One finds only occasionally on the beaches of the south shore very limited deposits of flattened pebbles composed of corals. fragments of æolian ledges, and shells of Nassa.

We can readily follow off the north shore of St. George the transition of the æolian shore ledges into mushroom ledges, or other patches gradually becoming coated with coral growths as they come nearer the main channel into deeper water towards Murray Anchorage. We find here also a few serpuline atolls and fragments of vertical walls protected by Algæ or other growths. Sargassum, Algæ, and Corallines are especially abundant on the inside ledges.

The ledges I have examined immediately north of the main channel, the southernmost patches of the connecting ledges, all present a very similar structure. They are deeply eroded on the sides and surface. Sometimes one side drops nearly vertically from a depth of two to three feet at low water to six or seven fathoms. The top is more or less flat, resembling the ledges near shore, and differing from them only in being covered by a thick growth of Algæ and Corallines, which protects their sharp edges and ridges from the effects of the sea. The other faces are more or less sloping, dropping in steps much as the shore cliffs do, and they are more or less undermined and honeycombed. One can sometimes trace what may perhaps have been the low-water shelf of the ledge before the subsidence had reached its present height, when it was a part of the old shore line cliff, or one of the outlying rocks or islets.

On the Devil's Flats there are large patches which have in some cases been covered with bank sand, leaving the æolian rocks exposed only on the outer edges, where they are covered with the usual coral growth. In Port Royal Bay, in Great Sound, and in Hamilton Harbor there are many rocky patches rising above the sandy bottom on which Oculinæ are growing. Along the north shore the rocks are generally thoroughly honeycombed immediately above high-water mark; between that and low-water mark they show signs of abrasion and of the solvent action of the sea. The low shore cliffs usually extend from low-water mark outwards in shelves of very varying width, terminating either abruptly, or passing into deeper water, either by one or more steps, or by a gradual slope. The shelf immediately above low-water mark is usually protected against abrasion by species of Algæ, or small barnacles, or patches of Serpulæ or Mytilus, or a thin coating of Nullipores, while below or at low-water mark Sargassum and coralline Algæ begin to grow.

It is easy to trace out on the chart the former connection of the flats with the present land surfaces in all directions. The evidence obtained from an examination of a number of ledge patches between the north shore and the south side of the main ship channel is most conclusive that all these patches are only æolian ledges, parts of the cliffs which once were connected with that shore and have become separated from it by causes similar to those now acting upon its cliffs. Upon these ledges have gradually grown Algæ, Corallines, a few Porites, Gorgonians, and Millepores. When the patches are close to the shore Algæ predominate.

The shore cliffs extending into the sea usually have vertical or steep faces, and one can readily follow their indented and honeycombed outlines to a depth of three to four fathoms or more, where the base of the cliff passes abruptly into the coarse bank bottom. An examination of the patches to the north of the main ship channel shows ledges with the same structural features, except that their surface is more thickly coated with corals, Corallines, and Algæ, as well as Millepores; we find also a few indistinct serpuline atolls on these patches, but their number cannot be compared with those of the south shore. Many of the ledges are only protected by small barnacles and Algæ. Off Bailey's Beach there is a row of isolated cliffs and ledges forming an outer barrier to the bay, the remnants of the hills which once separated what now forms Bailey's Bay from the sea. The interior patches of ledges are more isolated; they stand out vertically, or nearly so, in from five to six fathoms of water, while those in deeper water nearer the outer belt of ledges may be more or less choked and covered up by the masses of coralline and æolian sand constantly accumulating and forming there.

Some of the ledges which are not too far removed from the shore line, like those off Bailey's Beach or some parts of the north shore off Spanish Point, are most instructive as showing ledges which still are capped by æolian pinnacles, of which the æolian stratification is most distinct. In the submerged base of these pinnacles the stratification has completely disappeared, and between high and low water mark the æolian rock has been changed into a hard compact ringing limestone, more or less worn and honeycombed by the solvent, as well as the mechanical, action of the sea. This irregular honeycombed and cavernous surface extends to the base of the ledge, where it passes into the coarse bank bottom. The base of the ledge may spread somewhat, or it may have been greatly denuded above low-water mark, so as to form a wide base for the æolian pinnacle surmounting it. The interesting feature, however, is to trace the gradual increase of coral and Gorgonian as well as Nullipore and Coralline growth upon these ledges below low-water mark, as we examine them both in deeper water and at a greater distance from the shore. So that when we reach a certain distance from shore where ledges surmounted by æolian pinnacles are rare, and where we find only ledges reaching up to low-water mark, we soon pass into the coral patches, where the coral growth has become so vigorous that it appears at first glance to have been itself the builder of the patches, having so completely buried under its coating the æolian ledge which constitutes its foundation. Unless one has traced the gradual development of these coral patches from æolian ledges through all their transitions, such an interpretation would be most natural.

The rocks and ledges off Craw Point out to the ship channel, and the rocks and ledges off the north end of Shelly Beach (the Stags), leading to the outer patches as far as the south side of the main ship channel, all tell the same story. We have everywhere the gradual change of an æolian cliff which has become detached from the shore passing into a ledge, and, according to the distance from the shore and depth of water becoming a ledge coated with Millepores, Algæ, Corallines, and coral growth, known as " coral heads." The more massive corals and forests of Gorgonians thrive better on the patches near the flats, or on the ledge flats themselves. There is a fine lot of patches to the westward of Mangrove Bay; they are æolian ledges close to Ireland Island, which gradually pass into coral and Gorgonian patches as one goes to the westward.

To the west of Mangrove as well as to the west of Daniel Island the patches are in comparatively shallow water, and are surrounded by great stretches of sand, the ledges being more widely separated and cropping out in greater number close to the outer edges of the sand flats. Gorgonians and Millepores flourish mainly on the inner flats, while corals grow, but not in abundance, on the outer ledges. These sand flats with pretty steep slopes seem to be due to the disintegration of great numbers of ledges which must have yielded more readily than ledges elsewhere on the bank to the destructive agency of the sea. An examination of the ledges of the great sound bounded by the Daniel

Island Flat shows them to be similar to those of corresponding position which we examined off the north and south shores of the main island, and there is nothing to show that they, any more than the ledges just mentioned, owe any considerable part of their increase to coral growth. We found here many patches of limited extent, with nearly vertical or steep faces, greatly honeycombed, and worn and covered with Algæ, Corallines, and coral growth, some of them rising from seven fathoms up to near low-water mark.

The corals on the ledges of Brackish Pond Flats increase in profusion on the patches as they increase in distance from the main channel. But the appearance of the animal and vegetable growth on the ledge is practically the same on all the ledges of the Bermudas; it is a question of quantity mainly. The greatest profusion of corals and Gorgonians, as far as I have observed them, has been found on the ledges of the flats of the northern, northwestern, and northeastern parts of the banks. The ledges and patches to the west of Ireland and Somerset Islands are connected with the patches to the westward, and form a continuous line of flats as far as the Western Reef Flats. They constitute a series of proto-Bermudian cliff ledges which have been worn away from the shore cliffs, or from the edges of former lagoons and sounds, and have been overgrown by a thin veneer of corals, Millepores, and Gorgonians.

The west shore of Somerset has been greatly encroached upon by the sea; its northern extremity has been divided into a number of islands terminating with Ireland Island and the islets flanking it. One of its extensions forms the western line of rocks and islets of Mangrove Bay. It was formerly connected with the spit running from High Point to Wreck Hill, but the sea has eaten its way through, and the islets running north from Wreck Hill are the western barrier of Wreck Bay. All along the shores numerous mushroom-shaped rocks are seen, either isolated or still connected by a basal ledge, especially in the ledge running south of Daniel Island. From Wreck Hill Bay to Ireland Island innumerable ledge patches are found, with from two to six fathoms between them. These patches extend in a wide flat to the westward, forming what is known as Elies Flat until they join the western ledge flats to the eastward of Chub Cut, where there is a narrow and somewhat intricate channel with four to five fathoms of water leading from the inner waters to the outer bank. This channel separates the Western Ledge Flats and the flats to the eastward of the Blue Cuts. The bottom of the channel is covered with massive corals, Gorgonians, and Algæ. An examination of patches which reach out from the shore, and have been disconnected from it but comparatively recently, gives us the key to the formation of coral heads and of the ledge flats. Many of these patches are not as yet covered with coral growths of any kind, and their origin can still be plainly traced. From these we pass to more distant patches, in somewhat deeper water, on which Millepores, Gorgonians, Algæ, and corallines have begun to obtain a foothold, but of which the ledge structure is still apparent. Some of the ledges and patches on the north side of Spanish Point show admirably the passage from the æolian rock cliffs, which have fallen into the sea covered only with a thin coating of Algæ, to ledges with a more abundant growth of Corallines and Algæ, and finally to patches with corals and Gorgonians at a greater distance from the shore.

The mouth of Wreck Bay is protected by a number of islands running across the opening of the harbor, the remnants of the land which once connected Somerset Island with the main island. The rocks and islets to the westward of Mangrove Bay are the continuation to the south of a series of ledges which connected it once with Ireland Island. Traces of the proto-Bermudian land are found in the many patches of ledges to the westward of Ireland Island which extend towards Green Flat and thence to the west of Mangrove Bay, reaching out to Cow Ground Flat. The patches between Wreck Bay and Daniel Island reach out to Elies Flat and connect with the Chub Cut Flat. They are the northern boundary of an extensive sound bounded on the south and west by the flats reaching to the westward of Hogfish Cut, and sweeping northerly east of the Chub Heads to join the Western Ledge Flats. Similarly, south of Chub Cut, Elies Flat is the sunken boundary of a smaller sound bounded on the north by the western extension of the Cow Ground Flat.

On the western ledges we find large patches of sand intervening between the ledges on which corals grow; sometimes these sand patches form long sand bars with coral-bearing ledges only on the windward edges, the lower ledges having been triturated into sand which is more or less shifting according to the direction of the wind.

The formation of the sand flats from the disintegration of the æolian rock ledges shows how little material the corals have supplied to form the flats; they often come up close to low-water mark, and yet no coral sand islets have been formed anywhere on the ledge flats, either near the outer reefs or on the interior flats. These sand patches gradually pass into the ledges forming the outer flats, where the coral growth is most abundant and gradually diminishes on the sloping ledges of the sea face to a depth probably of twelve fathoms. The finest corals and Gorgonians appear to have their limit at a much less depth, in from five to seven fathoms. Beyond this depth the broken ground sets in, which the fishermen state that they can trace to seventeen or even twenty fathoms.

The ledges on the sides of the causeway connecting St. George with the hills to the east of Harrington Sound, together with the flats which connect them, indicate the former existence of a chain of hills which have been disintegrated. These flats form the platform of the east and north sides of Castle Harbor, and they give us an explanation of the sand flats to the westward of Ireland Island. The causeway flats are literally packed with coralline Algæ.

To the northwest of Western Blue Cut there is a stretch of coral covered ledges, which, like the ledges to the north and east of a line running west of Ireland Island, are somewhat isolated, and have remained disconnected from other ledge flats. They have not, like the Devil's Flat, and those to the westward and southwestward of them, been pounded and ground up to form coarse sand ledge flats with steep slopes, from the surface of which scattered æolian ledges barely project high enough to allow a scanty growth of Millepores and Gorgonians.

On the inner side of the reef massive corals do not as a rule seem to exist beyond four to six fathoms, the point at which the great expanses of coralline bottom begin, and which extend nearly unbroken to the greatest depths of the inner waters on the banks.

The greatest width of the belt in which corals grow from the inner edge of these flats or patches to the outer six or seven fathom limit is about three miles at the eastern extremity. This is nearly the width of the land and water belt included between the island of St. George and the entrance to Castle Harbor. The belt between Ireland Island and Gibbs Hill is however considerably wider than any of the ledge flats. At the western end it is not more than a mile, the ring of ledge flats being widest west of Mills Breakers, and diminishing towards North Rock. The ledge flats are much narrower along the whole western and southwestern face of the Bermudas. The gradual shelving slope of the ledges which have been abraded on the sea face of the flats is well seen between the entrance to Hogfish Cut and the Western Blue Cuts. The Little Bar and Chaddock Bar form two wide spits with a gradual slope from two to seven fathoms, covered by Gorgonians, Corals, Millepores, and Algæ. Long Bar is a similar ledge, separated however from the Western Ledge Flats by a channel of from six to seven fathoms, the bottom of which is covered with corals and the attendant Algæ and Sargassum. These bars are full of just such ledges as have been described, only they have been the first to feel the effect of the inroads of the sea upon the proto-Bermudian land, and have been abraded to a greater depth. We find on their slopes as much as four to eight fathoms as a general depth; the channels between the ledges are in most cases overgrown with coral and Algæ. Outside of the six or seven fathoms at which they still flourish, Gorgonians and Algæ extend on the broken ground down to a depth of seventeen to twenty fathoms, with here and there an irregular sandy patch between the ledges. In the channels between Long Bar and Little Bar and the Ledge Flats, which have a general depth of six to eight fathoms, corals and Gorgonians grow in patches which are separated by coarse bank sand. The same slope similarly overgrown extends to the Chub Cut, and from the Western Blue Cut it becomes narrower towards the Southern Ledge Flats.

On crossing the Ledge Flats opposite the southern end of Long Bar, one meets the same ledges, but more worn and covered by a larger number of massive corals and Gorgonians. In the channel between the Southwest Ledge Flats and Long Bar, which is itself made up of patches similar to those of the outer edge of the Southwest Ledge Flats, the heads and patches do not come so near the surface, they form patches of massive corals, Gorgonians, and Corallines, or Algæ separated by areas of clear, coarse bank sand bottom. Such is the character of the outer rim of the reef, wherever we examined it, to the westward of Hogfish Cut, beyond Chaddock Bar, outside of Chub Cut, to the west of the Blue Cuts, outside of North Rock Flats, and to the south of Mills Breaker and off the outer reef of the south shore. The ledge patches and coral heads increase rapidly in height and number as we approach the outer edge of the flats and Gorgonians, Corallines, and massive corals become more abundant also in the spaces between the patches. The bulk of the corals and Gorgonians do not seem to grow beyond ten to twelve fathoms: beyond that depth Gorgonians, Algæ, and Corallines preponderate, and cover the bottom.

Off High Point extend the Bream and Kitchen Flat Ledges. They are like all the other ledges of æolian rock, with more or less vertical honeycombed sides. On Chaddock Ledge there is a depth of two to five fathoms. It is, like Long and Little Bars, made up of ledges in somewhat deeper water. It is continuous with the flat ledges to the west of Hog Fish Cut, and not separated from them by a channel. On Chaddock Bar there is a fine growth of Gorgonians, of Corals, of Corallines, and of Algæ, which stop in from six to seven fathoms, where we pass into the broken ground described above. The bottom of the channel of Hogfish

Cut in eight fathoms, as it passes out on to the bank becomes hard, and is covered with Thalassia.

On the inner edge of the reef to the north of Three Hill Shoal, starting from Mills Breaker Passage, we could observe in the close network of ledge patches no differences between them and those of other localities. The massive corals are perhaps finer and more numerous than elsewhere on the reefs. The Mæandrinas and Astræans are more abundant, as well as the Gorgonians, Algæ, and Corallines. The submerged faces of the reef ledges, as examined through the water glass, show no difference from those of similar ledges, such as we see rising from six to seven fathoms of water to a depth of two or three fathoms at low water, on which corals, Gorgonians, Algæ, and Corallines have not as yet obtained a foothold. In the deeper parts of the interior sounds, in from ten or more fathoms (sixteen at the outside), the bottom sand is much coarser than we find it in the shallower patches somewhat protected by the reef ledges, or in the reef bights in which patches of sand run in a considerable distance between the ledges. The reef ledges close to the edge, with nearly vertical or very steep sides, in from ten to eleven fathoms, are often separated by deep passages covered with sand, though occasional patches of Gorgonians and Algæ or Corallines grow over this bottom, and form connecting bottom strips between the ledges. A considerable amount of dead material accumulates at the foot of the reef patches and ledge flats, and, according to its position, is being slowly ground into the characteristic bank sand bottom composed of fragments of Millepores, Corallines, Algæ, Gorgonians, and Nullipores.

The "breakers" known as special rocks on the outer edge of the reef flats, such as Southwest Breaker, the Mills Breaker, North and Northeast Breakers, and many others, of which the North Rock is the most prominent, are the remnants of islands and islets or of ranges of æolian hills which once rose upon the outer reef flats, and surrounded the now sunken sounds, the lagoons and waters of the inner part of the Bermudas to the northward of the islands. They have by most observers been considered as owing their origin entirely to the growth of the corals we find thriving upon the surface of the ledges which compose these patches.

There are also three or four breakers bare at low water between the North Rock and the Pilchard Dicks. The Southwest Breaker is the westernmost of a series of ledges parallel to the south shore extending to the eastward as far as the entrance to St. George Harbor, the æolian character of which can readily be observed. The inner ledges extending from the south shore reef towards the main island are the remnants of the platforms of rocks once rising above high-water mark, or forming perhaps small islands, rocks, and islets across the bays of the proto-Bermudian land. We find to-day such islands and rocks separating Castle Harbor from the sea, those across the mouth of St. George, or islands belonging to an outer line of ledges which may be entirely disconnected from land promontories, or form, as they do across Whale Bay, Sinky Bay, and parts of other bays, an outer barrier protecting the south shore somewhat from the beating of the surf till they have crumbled and in turn been reduced to ledges bare only at low-water mark. The true character of many of the ledges forming the flats or the connecting patches is hidden by the coral growth. But both on the north and on the south shore we can follow the passage of the æolian rock ledges as they recede from the shore, from nearly bare ledges still connected with the shore cliffs to the coral patches. The ledge at Briggs Flat is mainly covered with Gorgonians and Millepores. We find there but few heads of massive corals; they are small Mæandrinas and Astræans, together with an abundant growth of Sargassum, Algæ, and Sponges. The Sponges are more abundant on the connecting ledges, if I may so call the patches extending from the north side of the main channel towards the flats, than they are upon the outer ledge flats.

As far as we can judge from such an examination as can be made in crossing the reef flats from the inner waters to the open sea, in the sections across the reef at Hogfish Cut, across the Western Ledge Flats at Little Bar and opposite the west end of Long Bar off the Chub Heads, across Chub Cut, across the Blue Cuts, across at the Northwestern Ledge Flats, across at the North Rock, Northeast Flats, Mills Breaker Passage, and the main channel, all the "coral heads" or patches seem to be growing on the tops of pinnacles of æolian rocks, or of flat ledges, or of mushroom-shaped tables, or of large irregularly shaped ledges rising sometimes gradually in irregular shelving strata, or in nearly perpendicular steps, from six or seven fathoms of water to near the surface.

Passing through Chub Cut to the outside of the reef, we find in four to five fathoms large Mæandrinas, Astræans, and fine Gorgonians, together with the usual accompaniment of Millepores, Sargassum, Corallines, and other Algæ. As we pass into deeper water the massive corals become smaller; in seven fathoms they are quite small and not numerous, and the whole bottom becomes thickly covered with Gorgonians, Corallines, and Sargassum.

An examination of the charts of the Bermudas will show many places outside of the reef to a depth of twenty fathoms which are marked rocky (*r*). These spots are most probably the outcrops of æolian ledges of the proto-Bermudian hill lands projecting slightly above the sandy bank bottom and forming a part of the broken ground. Beyond that depth (twenty fathoms) the lead brings up what is called coral bottom, made up in great part of æolian sand and of fragments of Corallines, Algæ, and the like. There are also patches of this rocky bottom inside of the reef ledges, as for instance close to the Western Blue Cut, where all the hauls of the dredge only brought up small quantities of the bank sand bottom.

The bottom over the Bermuda Bank is quite uniform in character. The greater part of it is covered with æolian sand of different degrees of coarseness, and more or less mixed with fragments of coralline Algæ and of Millepores or Gorgonians.

In other localities the surface of the old æolian rocky ledges is exposed, and is comparatively bare of æolian sand, as in some of the sounds, and the bottom may be called rocky. On this Oculinæ grow in profusion in the deeper waters of the sounds, or the more massive corals where the sea has free access to the sounds.

To the westward of Wreck Hill there is a small extent of bottom in seven fathoms of water covered with very fine mud, much like the white marl off Andros. A similar patch of marl occurs to the eastward of Ireland Island.

THE SERPULINE REEFS.

Plates XXI. to XXVI.

The serpuline reefs described by previous observers are perhaps the most interesting structures of the Bermudas. They are most numerous off the south shore, constituting miniature atolls and barrier and fringing reefs apparently formed by the upward growth of Serpulæ. While Serpulæ undoubtedly cover a great part of the surface of the structures, yet Algæ, Corallines, barnacles, mussels, and other invertebrates, are found to be fully as abundant as the Serpulæ, which in many cases play only a secondary part in the organic covering. In fact, it would be as correct in some localities to call them Algæ or Coralline atolls. Neither the Serpulæ nor the Algæ, nor any other organisms, have to any considerable extent built up the vertical walls of the different kinds of diminutive reefs so characteristic of the south shore. The

Serpulæ, Algæ, Corallines, and other growths have only protected the surface of the mushroom-shaped æolian rock ledges which form these structures from the action of the breakers. They have not built up the raised rims of the atolls, or the crescent-shaped or the horseshoe-shaped reefs, or the vertical walls forming the irregular convolutions and curves of the broader ledges.

Before my visit to the Bermudas I accepted the explanation given by older writers of the mode of formation of the atolls, as due to the accelerated growth of Serpulæ on their outer rim. I was therefore greatly surprised, on hammering at some of these structures, to find that the vertical walls were not built up, as is generally believed, of serpuline limestone, but were composed of æolian rock, and to discover that in many cases the elevated rim was protected by the hard ringing crust so characteristic of limestones exposed to the action of the sea, and further to find that the coating of Serpulæ, of Algæ, of Corallines, and of Nullipores was quite superficial.

Some of the serpuline atolls are circular and quite regular in outline, others crescent-shaped, while others are apparently formed by the accrescence of two or three atolls. Some of the circular atolls are symmetrical, with a central depression, at the bottom of which more or less sand has gathered. The rim of these atolls may project from a few inches to one and a half feet, or even more, from the nearly vertical base; its surface is completely covered by a thick growth of different species of Algæ, Zoanthidæ, Corallines, and Serpulæ. The rim varies greatly in width; in some cases it is not more than eight to ten inches, in others from one to five feet, and in some cases there is only a small circular pot-hole or a very circumscribed area left bare of growth in the centre. The rim is often greatly developed on the weather side, forming a crescent, tapering gradually to a thin wall on the opposite side. The crescent is often open for a great part of the circumference, the weak wall of rock forming its lee edge having been carried away by the breakers.

On the outer reef the ledges which are awash are similarly constructed. It is true there are few of the regular atoll shape, by far the greater number being long ledges of compound atolls made up of diminutive crescent-shaped reefs. Upon these ledges low vertical walls have been cut out varying from six to eighteen inches in height, following all sorts of curves, rising like a succession of **S**-shaped loops of circular or crescent shape, or re-entering curves, running in all possible ways, and which at first sight would appear to be all due to the growth of vegetable and animal life which covers the top and sides of the walls.

The Algæ, Serpulæ, Corallines, Mytilus, and the whole growth which goes to form the serpuline atolls, form but a thin coating upon the ledges of æolian material upon which they happen to have grown. Underlying this animal and vegetable coating we find the æolian rock, which on some parts of the ledge may still be protected by the hard ringing crust so characteristic of Bermudian and Bahamian limestone. The inner parts of the pool or atoll within the raised walls is composed of softer material, or of material which has not been protected by animal and vegetable growth from the destructive agency of the sea. The serpuline atolls are æolian rock ledges which once were a part of the south shore cliffs at the time when the shore line was farther to the southward and had not yet begun to yield to the inroads of the sea.

The protecting growth of the atoll has little to do with the formation of the wall forming the rim of the atoll ; in some cases it has undoubtedly grown up perhaps twelve to eighteen inches above the wall itself, but the deep lagoons and steep vertical walls of the serpuline atolls so characteristic of the southern side of the islands have been formed, I believe, by the mechanical agency of the breakers. These diminutive atolls are large pot-holes excavated by the surf and sand, and the varied forms of circular or of crescent-shaped reefs, of barrier reefs, and all the possible modifications one finds on the south shore of the Bermudas, are primarily due to the mechanical action of the sea. All these structures, from a circular or elliptical atoll to a barrier or fringing reef, with all their possible modifications, are due to the action of the surf and the sea in wearing away the surface of the mushroom-shaped rock, which is either softer than the surrounding parts or is not protected by the covering coat of Algæ, Corallines, or Serpulæ.

One can off the south shore trace the whole process from the time when the large fragments of shore æolian rock fall by undermining into the sea, until they are changed by the action of the surf into mushroom-shaped ledges surmounted by pinnacles, and next into the stage when the pinnacle has in turn been undermined and dropped alongside of the ledge to become the holding ground of coral and other growths. The surface of the flat ledge which formed the base of the pinnacle is now freely acted upon by the breakers. According to the nature of the upper crust, and to the extent of protection given to it by the covering coat of animal and vegetable life, the sea acts upon it, and we have hollowed out diminutive circular atolls, crescent or horseshoe-shaped structures, as well as the curved, straight, or convoluted or looped vertical walls of broader ledges which stand up from the bottom and seem to have been built up by the organisms covering the surface.

The serpuline atolls are of all shapes, depending primarily upon that of the slab from which they happen to be formed. We may imagine one of the shore slabs or ledges more or less overgrown with Algæ and Serpulæ exposed to the action of the incessant breakers of the south shore. The sea face of the ledge either slopes rapidly or is more or less vertical, sometimes undercut or worn to a mushroom-shaped table. According to the hardness of the protected edge of the ledge or of its surface, it becomes more or less broken through by incipient pot-holes, which expose the softer æolian rock to the action of the sea. With each tide the wearing action increases, until a circular pool is formed, in which sand is constantly triturating and grinding away the softer surfaces. Thus a miniature inner lagoon becomes excavated, not more than a few feet in depth, and surrounded by a more or less regular rim; the depth of some of the shallower lagoons varies from twelve to fifteen inches. On a ledge in which a pot-hole has been formed the sea thus washes at first into a shallow dish, or into a series of dishes which are soon run together, and thus a straight or curved or **S**-shaped vertical wall may be excavated on the edge of a ledge of æolian rock, the inside depth in one case being eight feet.

The serpuline atolls take their greatest development towards the western part of the south shore. Off Great Turtle Bay we find the same extraordinary development of the serpuline atolls and reefs which we traced farther to the eastward, off Hungry Bay and off Elbow Bay. There is hardly a sunken ledge on or along or off the south shore of which the surface is not protected in some way by Algæ and Serpulæ, and covered with structures which are directly the result of the action of the sea upon the friable æolian rock of which the ledges are composed. It is indeed a remarkable sight to see, as far as the eye can reach in either direction, this narrow belt of ledges which have been so strangely modified by the action of the sea and the protecting agency of the animal and vegetable growth upon its surface.

The presence on the south shore of so many striking circular atolls and horseshoe-shaped, crescent, or curved rings, or partial rings, and **S**-shaped walls, withdraws the attention from the far greater number of mushroom-shaped blocks and ledges which no longer reach the surface, owing to the wearing of the æolian rock of which they are composed. The atoll-shaped ledges have attracted more notice, not on account of their greater number, but mainly from the interest centring in such structures. For alongside the atolls, either rising to the surface, or near to it, or always covered at low water, there are other ledges, of endless differing shapes, which do not attract the eye, but which play as important a part in the economy of the ledges off the south shore as the atoll-shaped structures themselves, and which give us the clue to their formation.

Everywhere on the shores of the Bermudas where active degradation of the coast is going on we meet with a number of ledges, or pinnacles, or islets, or mushroom-shaped rocks, which have been fashioned by the sea into a nearly circular or elliptical form. Sometimes a number of these isolated rocks may stand in a row above high-water mark, the stems almost eaten away from the ledge upon which they stand. When the top tumbles over, the support, or a part of it, may remain well above low-water mark. It is upon these ledges of all sizes, from a foot or so in diameter to long elliptical or irregularly shaped masses of fifty to seventy feet in length, or even more, that the sea begins to act, and to shape the serpuline atolls of the south coast, though they are not confined to it, as I shall show hereafter. Standing on some parts of Elbow Beach, one may follow the irregular mushroom-shaped rock ledges standing between high and low water mark to those at and beyond that point into deeper water. We may note the changes which gradually take place as the protective growth upon these irregular ledges, at first bare, transforms them into the atolls, or crescent-shaped or **S**-shaped structures forming the reef off the south shore. One can watch at low tide and see the breakers combing in over the rim of the little atoll scouring the lagoon, and the superfluous water flowing over its sides. The sea breaks over the edge, carries off such loose fragments as may have been started by the preceding rollers, and scours the inside with the sand it may have brought in, in addition to what it finds inside.

Some of the crescent-shaped serpuline reefs are formed on ledges bare at low water extending out from shore. They form low vertical walls of from twelve to twenty-four inches in height, running in a series of irregular curves, a kind of festoon as it were, protecting the inner lagoon or lagoons of all sizes and shapes which have been gouged out by the waves. It is not uncommon on the south shore to find fine sand deposited on the flat ledges near low-water mark, and kept in place by the growth of a thin sward of Algæ; this, together with the thin crust formed over its surface, hardens the mass, keeps it in place, and enables it to resist the moderate action of the breakers.

Going westward from Great Turtle Bay to Warwick Bay we find the same condition of things, — an outer ledge of boilers together with irregular inner rows of ledges running close to the line of low-water mark, and gradually passing into the mushroom-shaped ledges which still form a part of the shore cliffs.

The district extending from Sinky Bay west and east is specially instructive, as showing the method of irruption of the sea through low shore cliffs to form small boat bays, and the gradual passage of these shore cliffs to lines of rocks and islets running parallel to the coast, and cutting out such bays as Whale Bay, Bailey Bay, Warwick Bay, Great Turtle Bay, etc. We may next follow the passage of these cliffs to submerged ledges, and their transformation into the boilers off the south shore and the outer line of boilers forming the so called reef off the south shore. The most striking of the serpuline reefs are the fringing and barrier reefs, and their outlying atolls, off one of the points at the east end of Whale Bay, together with the lines of atolls and variously shaped serpuline reefs extending to the eastward. Nowhere perhaps on the south shore do we see so clearly the transition of the isolated mushroom rock ledges surmounted by æolian pinnacles into the ledges which are to become serpuline reefs, as in the district between Great Turtle Bay and the bay at the foot of Gibbs Lighthouse.

From the descriptions given above of such a variety of reefs formed by the serpuline ledges, and of the action of the sea upon them, we may obtain on a small scale an illustration of the mechanical theory of the formation of some coral reefs. This may be specially applicable to the formation of compound atolls, as has already been suggested. We find off the south shore, in the same area and subject to identical conditions, patches which assume the shape of atolls of fringing or barrier reefs all within a stone's throw of one another. But in this case the structure of the foundation gives us the explanation of their formation, for the shape of these diminutive reefs is primarily determined by that of the ledge, and not by the growth of the Serpulæ. The different shapes of these diminutive reefs can be traced to the manner in which the sea has acted upon their æolian substructure. It may have only honeycombed the surface of a large cliff fragment, and left it as it fell, merely covering its diminutive spires and hollows with a thin layer of Serpulæ, Mytilus, Algæ, and Corallines. It may have washed off from the shore cliffs slabs of æolian rock in such a manner that as they lie on the beach the strata are horizontal, and, the edges having become cemented by the action of the sea, the division lines become obliterated, and over their surface has grown an animal and vegetable covering. It is not an uncommon thing to see on some of the beaches large slabs of base rock, upon the hard ringing surface of which grow Algæ; these collect particles of sand, and thus form a coating from a quarter to three quarters of an inch thick, upon which larger Algæ then flourish. In the intermediate spaces grow the Serpulæ, Mytilus, and Corallines, which soon conceal the surface of the ledge by their protecting coat. Should this slab alone or with adjoining slabs form an extensive ledge far enough out from the beach to be exposed to the action of the breakers, its nearly vertical sides would form a rampart over which the sea combs and pounds down over the edge of the slab, striking beyond the outer edge well toward its interior, according to the size of the breaker. If there exist at the points reached by the breakers any weak spot in the protecting crust, or any incipient fracture, or any difference in the hardness of the upper layer, the sea soon makes an inroad upon it. It grinds out the softer interior parts, which are carried off, and thus forms the beginning of a flat shallow saucer-shaped cup on the inner part of the ledge. The outer rim, on the contrary, protected either by a hard crust or by a growth of Algæ and of Serpulæ, remains intact, and gradually rises higher and higher, partly from the additional growth of the Serpulæ and other calcareous organisms, but mainly by the grinding away of the interior of the ledge to form a basin, which little by little becomes deeper. The organic growth on the outer rim is more vigorous than in the basin itself, either on its sides or on the bottom, where the sea breaks and is at work grinding away the protecting growth. The Algæ, Serpulæ, and other growths become less abundant in proportion to their distance from the outer weather rim, until, towards the centre of the atoll, the inner ring or cup or slope is covered with sand. We thus have diminutive atolls, barrier reefs, or crescent-shaped or horseshoe-shaped structures formed out of the æolian rocky ledges. Should the sea face of the slab be harder than the faces of the sides or of the leeward side, some of those strata are soon broken through, and gaps made in the rim, forming a crescent-shaped wall or arc with its greatest height seaward, the wall gradually falling to leeward to the level of the ledge, and the raised edge sloping towards the horns of the crescent on either side. The lee face of the crescent-shaped atoll is in such a case thoroughly scoured by the outward rush of the sea, which, carrying with it a certain quantity of the sand that fills the depression, runs off the lower lee side with considerable velocity. The depth of the atolls varies from a few inches to six feet or more. The lee faces of both horse-shoe-shaped and crescent-shaped atolls are frequently so rapidly removed as to leave nothing but a vertical wall of from one to two feet on the weather face of the ledge.

The diminutive reefs formed off the south shore of Bermuda are of all possible shapes, — atolls with regular rims of the same width on all sides, atolls with the sea face rim wider than that to the leeward, and parts of rims of circular atolls of horseshoe or crescent shape, or only of parts of arcs of greater or less extent. We also find belts of small atolls on ledges of considerable width, and atolls of an elongate type; others are dumbbell-shaped, formed evidently by the breaking through of division walls of circular atolls. We also meet with chains of atolls, each one forming a link as it were, or irregular parallel chains, which, when the separating walls are broken through, give the elements for all the possible figures assumed by the ledges off the south shore. When such reefs are formed on the shore ledges, we have all the possible types of fringing and barrier reefs, or combinations of these, forming diminutive reefs with low vertical walls apparently most irregularly placed, often as if their existence in their varying shapes and positions could be due only to the upward growth of the Serpulæ and Algæ. But I believe that the vertical growth of Serpulæ and Algæ is not of itself sufficient to account for the existence of the vertical walls, and that they are due only in small part to the upward growth of organic material, and in a great measure to the action of the breakers upon the æolian rock ledges, probably in the manner I have just described.

The barrier reef off the small spits to the east of Whale Bay at the Targets may be described as a vertical wall surrounding three sides of a rectangle, the diagonal of which is somewhat over fifty feet; the sea face corners are well rounded and the side walls formed of short arcs. The distance from the shore edge of the ledge to the outer wall is about twenty-two feet. The greatest width of the rim is at the two outer angles, where it varies from five to six feet; the inside edge of the sides of the rim gradually passes into the shore ledge, being in a general way parallel to the trend of the sides of the barrier reef. The raised part of the rim varies from twelve to sixteen inches in height. The outer vertical wall has a height on the west of eight feet, and on the east of about six feet, the slope of the ledge being more or less concentric round the deepest part as a centre, and sloping sideways towards the shore edge. The outer rim at two points is gouged out into two smaller elongated pits. The rim is everywhere well protected by Algæ, Corallines, and Serpulæ, the Algæ growing on the more or less level platform of the rim, and on the outer and inner faces of the vertical walls of the barrier reef. The ledge is greatly undercut, and its outer faces present all the irregularities of wear by water so characteristic of shore ledges. The inner slope is covered by a thin growth of Corallines and smaller Algæ, which do not seem to thrive as well as where they receive the direct force of the breakers. Close to the westward of this diminutive barrier reef are ledges which may be regarded as typical of the changes which have taken place in a bare æolian ledge just dropped from the shore cliffs until it becomes a typical boiler of the south shore. One of these is separated from the western edge of the barrier reef by not more than six feet, and has a depth of water of more than ten feet in the passage between them. To one side of this dumbbell-shaped atoll, which is nearly thirteen feet on its longest axis, is another atoll on a mushroom-shaped ledge seven feet in diameter, with a regular rim and a pot-hole of three feet in depth. This is separated from the adjoining mushroom-shaped ledge by a gap of four feet, with a greatest depth of ten feet, and eight feet on the shore edge; it is separated from the shore and a large ledge to the south by a deep passage of nine feet in width. The length of the larger ledge, irregularly shaped, is over forty feet, and its width varies from twenty to thirty-five feet. Its outline is formed by curved walls, the edges of irregularly shaped elongated or circular dumbbell-shaped pits gouged out from a broad platform of æolian rock. On the lee part of the ledge an irregular rectangular pot-hole has been formed, five feet in depth on one side and four on the other, sloping upward toward the broad outer rim. Comparatively slight variations would change the surface of the ledge into an atoll with a narrow rim following the outlines of the ledge; or it may become divided into two irregularly shaped pits by the coalescence of the few smaller pits now upon the platform, and a single curved wall, the remnant of the face of one of the circular pits, would form a division wall; or the sea may break through to a greater extent than it has done already and leave on this ledge only disconnected fragments of wall of varying shape, in which it would be difficult to recognize the walls once limiting circular or dumbbell-shaped pits. Outside of the larger ledge is a pear-shaped atoll with a broad sea face or rim sloping inward, and a circular pot-hole about three feet in depth, the rim of which is narrower to the leeward.

All these ledges are deeply undercut and abraded, and are mushroom-shaped; their faces are vertical or nearly so, and all show traces of the action of the sea upon the pillar forming the base. The ledges I have examined close to the shore, half-way to the reef, or on the outer line of ledges, all present modifications of the ledges described. Their ultimate shape depends upon many local factors, and they show but a small number of the possible intricate figures that are found on the æolian ledges off the south shore. The Algæ, Serpulæ, and other organic growths which thrive upon the edges of the ledges and spread down upon the vertical faces, still further protect the sides of the mushroom tables from being washed or eaten away by the forward and backward rush of the sea.

Off the same locality an elliptical atoll forty by thirty feet, standing in a depth of ten feet at low water, formed the spreading top of a mushroom-shaped ledge from the vertical sides of which all traces of the æolian character of the substructure had disappeared. Where not overgrown with Algæ and Corallines, it showed the peculiar gouging out and honeycombing character of all shore rocks, either when exposed at low water or where extending below it. The inner part of the weather rim was not quite parallel with the outer outline; it projected in the centre and was somewhat scalloped in outline, with a few small deep pits. The rim varied in width from five and a half feet on the weather side to one foot in its narrowest part on the leeward edge. I could not detect that the weather rim was perceptibly higher than the leeward rim, though this is not unfrequently the case.[1] The pot-hole was six feet in depth nearer the western edge, gradually decreasing in depth to three feet on the opposite side. A crescent-shaped lagoon eighteen feet in diameter, greatly undercut, especially on the weather side, as all these ledges are, had a rim five feet wide at its widest part, gradually tapering to four or five inches at the two extremities of the crescent. Both this and the elliptical atoll just described had a narrow shelving platform on the inside of the weather rim. The lee edge of this crescent-shaped atoll was worn away five feet lower than the weather rim. A circular atoll twenty-five feet in diameter was surrounded by an irregularly elliptical rim twice as wide on the weather as on the lee side, forming a scalloped pot-hole with a greatest depth of three feet. Along the

[1] Heilprin speaks of the Serpulæ as occurring "in dense bunches," and where the surf beats hardest "the Serpula growth was most largely developed, and to such an extent as to form a raised rim or barrier to the more protected inner side." But, as he himself says, (and I am not quite clear whether he attributes the formation of the atoll to the Serpulæ,) "the breaking in on all sides of the surf has created a number of more or less irregularly oval islets with depressed centres, or, more properly, with elevated borders." In the one case he says, "The depression is merely a negative one, being such by reason of a somewhat more rapid growth developed only from the water line, or within the surf," but he feels satisfied, however, that the two structures (these serpuline atolls and the coral atolls), while seemingly alike, have practically little or nothing in common.

south shore I observed a great number of ledges with nearly flat tops, from which the surmounting æolian pinnacles had been worn away; some of them were just awash at low-water mark, others reached half-tide mark, and a great number were sunken ledges. On these last, if forming the inner part of the outer line of ledges, are found Gorgonians and corals, giving them to a certain extent the appearance of a coral reef.

Off White Cliff Bay there is an excellent specimen of an irregular crescent-shaped barrier reef formed upon a ledge barely in contact with the beach at low water. The wall on the inside is formed of short irregular steps, and the inner area of the ledge is thickly overgrown with calcareous Algæ, more or less covered with æolian sand washed from the friable parts of the ledge.

The narrow pedestals which are the bases of some of the pinnacles of æolian rock are often the remains of extensive flat ledges on which the different organic growths characteristic of boilers have obtained a foothold. The parts of the tops and sides of these ledges which have not as yet been covered by such a growth, or only partially so, plainly show that they differ in no way except in size from the smaller mushroom-shaped æolian rock ledges, and are formed by the same agencies. The larger pinnacles of æolian rock like those still standing off Whale Bay will become, when they fall, large flat ledges upon which the sea when breaking digs out irregular pot-holes of all shapes and sizes. The remnant of the base of the pinnacle becomes, when worn away by the sea, either a shelf or a flat corrugated ledge, and the more or less vertical sides below low-water mark are worn away by the wash of the sea into mushroom-shaped ledges.

At the east end of Elbow Beach several patches of honeycombed shore rock ledges have been left stranded in the midst of the beach sand surrounding them. These ledges, if exposed to the action of the sea, would soon be worn flat, and according to the angle of their stratification would be dug out into atolls or other irregularly shaped structures protected by Algæ and Serpulæ. The same serpuline growths and similar convoluted walls occur on the North Rock and the adjoining ledges on the north. Similar structures, forming more or less distinct reefs, also occur off the north shore and elsewhere on the edge of the reef flats, but they are not as numerous nor so well defined as a rule. They consist, however, always of the same mushroom-shaped ledges, sometimes still surmounted by their pinnacles of æolian rock, and of others abraded to the level of low-water mark, or even well below it. The shore ledges on the south coast are acted upon by short, sharp breakers, formed in from one and a half to two fathoms of water, beating upon the ledges much as a small waterfall drops upon the rocks at its base. On the north shore the breakers and sea do not act with the same regularity as on the south shore. There, owing to the existence of an outer line of reefs, the conditions are more uniform than on the north shore, where the effect of the winds upon a comparatively broad stretch of sea are far more variable.

On the north shore the surface of the ledges between high and low water mark is protected mainly by a small species of barnacle, clusters of small Mytilus and incrusting Nullipores, and a few species of small Algæ. At or below low-water mark Sargassum begins. Serpulæ are not as common as on the ledges off the south shore. On the north shore serpuline atolls are most numerous on the ledges off Spanish Point in an easterly direction for a distance of four or five miles.

The mode of formation of the peculiar and intricate windings of the vertical walls which crop up to the surface on the summits of the ledges, and which take on such complicated curves can readily be explained from the manner in which the ledges themselves yield to the action of the surf from the wash of the sea, and also from the angle at which the æolian strata lie when attacked by the waves.

The following diagrams will further explain the mode of formation of the various serpuline reef structures which have been described.

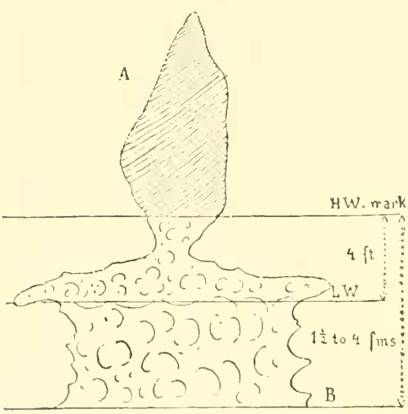
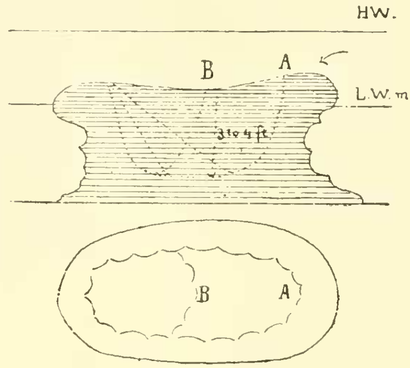


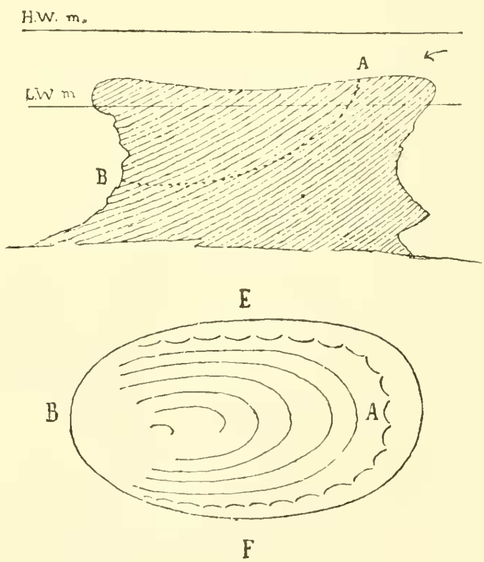
Fig. 1.

AB (Fig. 1) is a piece of shore cliff which has become isolated from the shore; the æolian lamination is clearly seen above high-water mark. Below high-water mark it is honeycombed and eaten away, leaving the æolian pinnacle supported only by a slender stem rising from an extensive base more or less covered with Algæ, Serpulæ, and other growths. The surface of the ledge, as well as the base of the mass extending below low-water mark, is more or less eaten away, and when the æolian pinnacle (A) has fallen off a mushroom-shaped mass is left, the upper surface of which may be above or below low-water mark. All trace of æolian stratification has been obliterated by the cementing and solvent action of the sea water. If the base, the mushroom-shaped ledge, is stratified horizontally (Fig. 2) the result of the wash of the breakers upon any part of the top left unprotected will be to dig out circular or elliptical atolls (Fig. 3) like A or B. In one case, A, the atoll will have a rim of nearly the same width, while in the other case, B, if the softer parts of the top are on the lee side, the atoll will have a wider rim on the weather side from B to A, or a pot-hole may also be formed between A and B. The pot-holes of these circular atolls are usually from three to four feet in depth. But in some cases I have measured them between five and six feet, and even more. In others they are only a few inches deep. I have not observed any growth of Serpulæ of greater thickness than from twelve to eighteen inches.



Figs. 2, 3.

Should the æolian strata dip towards the lee side (Fig. 4) a horse-shoe-shaped atoll is formed, as indicated by the dotted line AB. The rim is widest at A, Fig. 5, gradually becoming narrower and lower towards the lee side as it nears B, the whole or the greater part of the ledge having been carried away by the pounding of the surf, leaving



Figs. 4, 5.

a high narrow wall with a deep opening at B between its extremities. Should the surf break through the sides at E or F, or both, we should have curved vertical walls left, apparently built up by Serpulæ, in reality walls of æolian rock which may be dug out as I have suggested, either in the case of Figure 2 or of Figure 4.

When the pinnacle finally drops off, it will in its turn be attacked by the sea, and go either to form a smooth ledge, to be covered with Algæ and Serpulæ according to the depth in which it lies, or may in its turn be attacked in a similar way to the ledge, and changed to an atoll or a crescent-shaped serpuline reef according to the dip of the strata. Before the breaking off of the pinnacle, Algæ and Serpulæ have already begun to grow upon the flat part of the ledge, and protect it to a great extent from the action of the sea. When the sea no longer washes round the pinnacle, but breaks on the ledge at low water, and finds a part which is not protected by Algæ or otherwise, it begins to erode it, the sand formed acting like a churn, and thus little by little forming a deep hole in the centre of the mushroom rock.

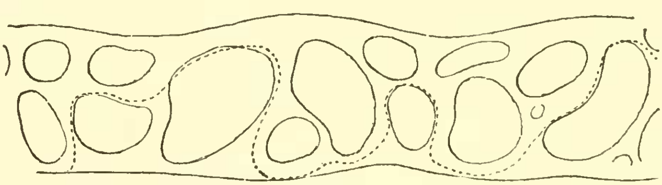


Fig. 6.

In the case of a long and wide ledge, there are formed upon it a number of secondary pits and atolls, or pot-holes, as indicated by the heavy lines of Figure 6. Let the walls of these break through and connect adjoining pot-holes and we obtain a vertical wall, of irregular outline, such as is indicated by the dotted line of the figure, which is a diagram of one of the ledges of the outer reef off the south shore. The wash of the sea may break through the continuous wall, leaving only disconnected parts standing, or we may have the outer walls on the edge of the ledge left, forming a long trough.

A flat ledge projecting from the base of a shore cliff, if eaten into in the same way by the surf (Fig. 7), may be worn into a circular reef with vertical walls, of which the top is protected by Algæ and Corallines or Serpulæ, with a pot-hole near its outer wall, in this case eight feet deep. We might call this a diminutive barrier reef. If the walls are parts of diminutive barrier reefs, the shore cliff behind them may disappear, and thus leave a wall standing apparently isolated from the level of the ledge. It is not surprising that a cursory examination of these walls and atolls should have induced the earlier observers to attribute the growth to Serpulæ.

Rice accepts the theory that the serpuline reefs are due alone to the upward growth of Serpulæ. He has also observed the circular ridges of coral on the outer ledges (Millepores) similar to the serpuline reefs, except that they are less elevated, their upward growth being limited by the inability of the corals to survive an exposure above the water. These circular reefs are either serpuline or edged by Millepores, and are called boilers; off the south shore they are generally serpuline, with only here and there a Millepore boiler on the inner patches. Along the east shore of Harrington Sound there are a number of such Millepore atolls and barrier reefs which are merely rims of pot-holes protected by a growth of Millepores. A number of these Millepore reefs extend eastward on the northern side of the main channel off Spanish Point. Along the shores of Harrington Sound we meet occasionally one of the vertical walls or irregularly shaped pot-holes of a projecting ledge, the top of which is protected by a growth of Millepores, much as the Serpulæ and Algæ protect the walls of the pot-holes off the south shore. On many of the patches to the north of the main channel, in a line from Ireland Island to St. George, we find a similar growth of Millepores protecting the exposed ridges of æolian rocks. Thomson also considers the serpuline reefs as due to the agency of Serpulæ.

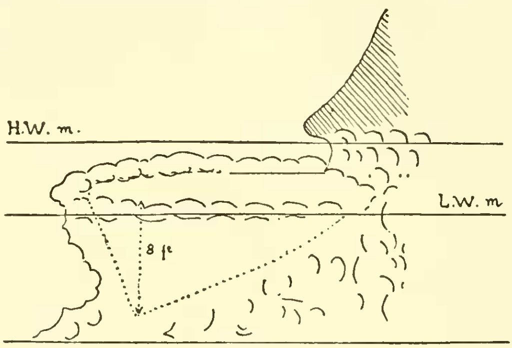


Fig. 7.

The existence of such a variety of reef forms under the same conditions naturally suggests whether the explanation by mechanical causes, such as finds here its application on a small scale for serpuline reefs, may not be a natural explanation also of the formation of the complicated systems of atolls of the Carolines, Marquesas, and Maldives, and whether small simple atolls like the typical ones of the Pacific, and many with complicated outlines, may not in many cases be due to the scouring action of the sea working on a larger scale upon substructures easily yielding to its effects. When examining the Hogsty Atoll of the Bahamas I could not fail to be struck by the overpowering mechanical force incessantly at work. Huge breakers were constantly pouring an immense volume of water over the windward sea face of the atoll, filling its cup to overflowing, and it could find no outlet except over those parts of the sides which were lower than the windward face, or through which, near the lee ends, passages of considerable depth had been eroded, or, finally, through the still deeper channel between the lee extremities of the reefs forming the entrance to the atoll. That is, given a bank of suitable depth upon which corals can flourish, and upon a belt of a certain width, they will form a protective coating to the underlying rocks, just as the serpuline growths protect the rims of their diminutive atolls. Corals will naturally, from the centrifugal action of the sea, grow on the outer faces, and most abundantly in the direction in which they find least resistance in the way of detritus and other accumulations. The sea breaking over them will excavate a lagoon, and break through the sides or lee face to allow the water to flow out through the points of least resistance, and through the entrances to the lagoon. All these causes are important factors in any theory of coral reefs, and show the complexity of the problem, and the impossibility of framing a single hypothesis to explain the formation of coral reefs in all parts of the world.

Before seeing the serpuline atolls of the Bermudas it had occurred to me that the configuration of the Hogsty Reef and the formation of its atoll might be due to mechanical causes. We may imagine a bank of the proper depth, whether formed during subsidence or elevation is immaterial, on which corals begin to grow and form a barrier to the surf. The breaking of the surf over this living and protecting barrier digs out the least resisting portions of the surface of the bank, and the material thus dug out finds its way out on the opposite side. Little by little a lee channel is thus formed by the scouring of the mass of water poured over the reef into the incipient lagoon, and a lagoon may be formed on a large scale in the manner described for the formation of the serpuline lagoons of the Bermudas. We may imagine the Hogsty Reef at one time to have been a bank formed by a series of small, low æolian hills, which have been worn away and have disappeared from the same causes which acted on a larger scale at the Bahamas. The Hogsty Bank was thus brought by subsidence and erosion to its present level, or nearly so, after the growth of a barrier of reefs on the remnants of the æolian hill ledges, then began the action of the surf in eating away the central part of the bank, scouring the lagoon to the depth and dimensions it has now attained. There is nothing to show that the depth of the lagoon of Hogsty Reef is due to subsidence, or that the rate of growth of the reef was synchronous with it, and thus formed the outer rim of the lagoon. On the contrary, judging by analogy and by the conditions existing in the Bahamas and Bermudas, we are led to infer that the lagoon of Hogsty has been formed by a mechanical process, that it is due to the action of the surf acting as an immense force pump driving the water over the weather face of the reef[1] out through the lee opening of the lagoon, or the openings of the sides of the ring, much as the diminutive serpuline atolls and crescent-shaped reefs or barrier reefs have been formed off the south shore of the Bermudas.

POT-HOLES.

Plates XXIX., XXX.

Roots and stems, after being decomposed, may form branching cavities which if filled with stalagmitic matter would give rise to columnar structures. Such formations can be traced in the more recent dunes of the Bahamas and Bermudas, and of the Sandwich Islands. There is a type of pot-hole which imitates these structures[2] and has been confounded with the branched bodies, but which I do not believe to be organic structures at all.[3] They are the so called palmetto stumps, of which Rice has given an excellent description,[4] and which I imagine to be mechanical structures of a similar origin with the serpuline reefs (Plate XXX.).

To the north of the Devil's Hole, on the road skirting the east shore of Harrington Sound, we find a flat ledge of æolian rocks which is literally

[1] That water falling from a small height does thus excavate deep holes at the foot of falls is well known. Any country ditch dammed by a sluiceway will show this effect. It can be seen at the foot of every waterfall, and it occurs on the largest scale in the Mississippi, where the scour of the river below New Orleans has since the building of the jetties excavated a depth of between sixty and seventy feet in some cases, — a depth about the same as that of many lagoons of coral atolls.

[2] I cannot agree with Thomson (Atlantic, I. 330) in his explanation of the mode of formation of the pseudo palm stems, who considers them to have been formed on the bottom of caves by the dropping of stalagmite, and thus forming a single or double or dumbbell-shaped stem.

[3] Are not some of the tubes to which Professor Dolley ascribes a vegetable origin merely small pot-holes such as I have figured on Plate XXIX.?

[4] Bulletin of the National Museum, No. 25, p. 27.

riddled with pot-holes, many of which have become connected to form dumbbell-shaped cavities or other irregular forms (Plate XXIX.). They are in every respect similar to the serpuline atoll pot-holes off the south shore, but are much smaller, and become changed many of them into the so called palmetto bases.

An irregularly shaped pot-hole with a raised rim is one of the prominent features of one of the ledges on the north side of the causeway leading to St. George. In this case the greater hardness of the rim has formed the protective coat for the low vertical wall of the pot-hole (atoll). The transformation is readily followed in the pot-holes which are a little removed from the immediate action of the diminutive, but short and sharp, breakers of Harrington Sound. The inner cavity of the pot-holes becomes lined with a harder coating, being acted upon much as is the surface of the æolian rock. When the walls of adjacent pot-holes are eaten away or worn away by the action of the rains and of the sea, there may be formed an outer coating from the adjoining pot-hole, and thus an irregular cylinder will be left standing above the surrounding area. If the upper part of this is in turn disintegrated, we may have left a deep cup, or merely a ring of the base, or a side of the cylinder, or merely the harder inner coat of the bottom, — all of which stages resemble more or less the base of a palmetto (Plate XXX.). These pot-holes are often so close together (Plate XXIX.) that it is difficult to imagine a grove of palmettos the stems of which could be packed in the area occupied by the pot-holes. Captain Carr, R. N., called my attention to a locality on the east shore of Ireland Island where these pot-holes are numerous, and where one can trace all the transition stages just described from the pot-holes of the shore of Harrington Sound.

NORTH ROCK.

Plate VIII.

The North Rock is undoubtedly the most interesting monument left of the former extension of the Bermudian land. Owing to the difficulty of landing, it has not been visited frequently, but we were twice successful in landing at the North Rock Ledge.

Excellent descriptions of the North Rock pinnacles and ledges have been given by Rice,[1] and also by Heilprin in his volume on the Bermudas.

[1] Bulletin of the National Museum,

The flat ledge surrounding North Rock presents no features different from those of similar ledges off the south or north shore. Its surface rises here and there in low ridges, which are the remnants of the last pinnacles to be eroded; near the edges, and wherever the action of the breakers reaches, it has been dug into so as to form pools, pits, and potholes of various depths and shapes, and has been honeycombed in all directions, according to the quality and hardness of the rock and the extent of the protection afforded the rock surfaces by the growth of Algæ, Corallines, Serpulæ, and other organisms.

The North Rock Ledge is deeply undercut, and, like many of the larger islets off the main island, its sides are more or less vertical, or steep slopes deeply honeycombed and cavernous, and overgrown with Algæ, Corallines, Gorgonians, Millepores, and massive corals, much as any similar ledge or cliff or patch. The greater part of its upper surface is protected by the hard ringing æolian rock characteristic of the exposed intertidal spaces. The pinnacles which remain rising above the general level consist of æolian rock, and the lower base rock seemed to me to differ in no way from similar æolian rock as modified by the action of the sea in other localities. It is possible that the fossil Cypræas stated by Rein to have been found at the base of the pinnacles may be only such shells as have been collected from the serpuline rock in which they had become embedded. In some spots on the ledge it attains a thickness of from twelve to fifteen inches, and is full of boring Mollusks and of shells which have found a foothold in the cavities of the honeycombed rock. The serpuline rock itself often becomes quite hard, and might easily be mistaken for true hard ringing æolian rock, but is readily distinguished from it by the presence of the many sharp pinkish fragments of the tubes of Serpulæ.

The many Chamas and other Mollusks living on the edge of the North Rock Ledge at low-water mark would, if thrown up and embedded in æolian or serpuline rocks, present all the characters of the so called fossils found in the æolian rocks of the islands of Hamilton Harbor. At Agers Island and on the shores of the other islands of Hamilton Harbor we find at very low tides many specimens of Chama which would have to be carried but little way to become æolian fossils. Neither Heilprin nor myself found any fossils on North Rock. Heilprin considers the lower portion of the North Rock pinnacles to be unquestionably pits and potholes of the inner surface of the beach rock.

The outer edge of the northeastern part of the ledge is protected by Serpulæ, Algæ, and Corallines, forming low vertical walls as well as the division walls of the irregular pot-holes of the ledge, and in places they overhang to a very considerable extent. The coating of Algæ and of Serpulæ on some of the walls of the interior pools is quite thin, as upon breaking off the edges we came upon the ringing æolian rock. On the northeast edge of the ledge a deeper pot-hole has formed a regular barrier reef, the edges of which are covered by Serpulæ, Algæ, and Corallines. On the interior of the ledge their growth is less vigorous. Outside of North Rock there are a few ledges, both to the southwest and to the northeast. Those towards the inner side of the reef are the outer reef patches, on which grow Millepores, Gorgonians, and the usual growth of corals, Algæ, and Corallines, which have completely hidden the nature of the ledges. The ledges which form the continuation of North Rock to the east and west, on the contrary, still plainly show that their structure in no way differs from that of the North Rock Ledge. Outside of North Rock " broken ground " extends to ten or twelve fathoms, but no patches of corals could be seen beyond five or six fathoms. We might call the outer ledges of the reef near North Rock a flat of coral heads and of Gorgonians. On the North Rock Ledge flat, Zoanthus, Millepores, Algæ, and Corallines are most flourishing.

Winding our way towards St. George Island from the North Rock, we picked our passage between the many mushroom-shaped ledges. Many of them came to the surface or nearly so, and on two of the ledge patches rather nearer the inner line of the ledge flats than to the North Rock I broke off a piece of hard ringing æolian rock in every respect similar to that of the North Rock Ledge flats.

We could not have a better example of the true nature of the reef ledge flats and patches than is exhibited by the North Rock Ledge and the adjoining patches. Those of the ledges nearest to the North Rock show the hard ringing æolian rock which marks the North Rock Ledge ; some of the patches are separated from it by water five to ten fathoms deep.

We can easily imagine the whole of the ledge flats of the vicinity to have been made up of æolian rock ledges and pinnacles, very much like those off the north shore, on which corals, Gorgonians, and the like have little by little become attached, and have finally grown over not only the sides, but the upper surface after it became eaten away well below low-water mark.

There may have been on the northern reef flat ledges lower lines of hills than those now existing on the Bermudas, or low hills like those separating St. George and Castle Harbor, or along the west end of St. George Island and on the north side of Harrington Sound.

PROTO-BERMUDA.

Plate II.

Rein, Thomson, Rice, Fewkes, and Heilprin, all agree to the former greater extension of the Bermudian land, and Thomson,[1] speaking of the North Rock, and of Pulpit Rock off Ireland Island, says there can scarcely be any doubt that the dry land of Bermuda at one time occupied a space considerably larger than it does at present.

We may readily reconstruct the proto-Bermudian land from the existing charts (Plate II.). Beginning with the line and clusters of islands running from Ireland Island to St. David Head, these must in earlier times have been somewhat wider. The main island must have extended south beyond the line of the reef, and dry land must have completely barred the access of the sea to the sinks which on the east constituted Harrington Sound and Castle and St. George Harbors, St. George Island itself probably forming the western edge of the Ship Channel valley. On the west the main island reached to Hogfish Cut valley, and Somerset and Ireland Islands were probably connected with a range of æolian hills running from Chub Cut across Elies Flat. On the east, Ireland Island was connected with Spanish Point by a ridge which isolated Great Sound, Port Royal Bay, and Hamilton Harbor sinks from the outer lagoons, Great Sound and Hamilton Harbor both probably being disconnected sinks, and both isolated by low saddles from Great Sound sink. The ledge flats to the west of Hogfish Cut and to the north of Chaddock, Little, and Long Bars, which pass to the east of Chub Heads as far as Chub Cut, formed, in connection with the Elies Flat, hills of which the ledges are the remnants, the barrier separating a great sound larger than any now existing from the adjoining proto-Bermudian sounds. Of these we can trace four others of great size. One bounded on the southwest by the hills of Elies Flat, on the northwest by the hills of the ledge flat extending north from Chub Cut, on the north by the line of flats running east in the direction of Three Hill Shoals till they strike the eastern face of the sound formed by the Brackish Pond Flats, the eastern boundary reaching towards Spanish Point and separated from the shoals north of it by the Ship Channel valley. The second sound is enclosed by the Brackish Pond Flats on the west, by the Bailey Bay Flats on the north and east, and by the main island on the

[1] Thomson, The Atlantic, I. 318.

south. The third is the Murray Anchorage sound, limited on the west by the Bailey Bay Flats, on the north and east by the Three Hill Shoals and the flats west of Mills Breaker. The third sound opened by a narrow deep valley (the Ship Channel) towards the sea, and communicated by a wide passage with the fourth sound, bounded by the ledge flats of the northwestern part of the Bermudas, — flats which extend unbroken from the north of Western Blue Cut to the Eastern Ledge Flats, — and on the southern edge by the line of the Three Hill Shoals and by the western extension of the Bailey Bay Flats. This fourth sound is in reality a double sound, as the western part is separated from the eastern by a narrow line of æolian heads, indicating probably the position of a cross line of dunes connecting the Ledge Flats and Bailey Bay Flats. Its northern edge was deeply indented, as is indicated by the many tongues of deep water cutting into the width of the ledge flats (Plate II.). Two smaller and indistinctly connected sounds are similarly indicated to the west of East Ledge Flats and to the west of Mills Breaker. On the eastern ledge flats there are also a number of deep pockets, already referred to, as well as many deep bights running into the ledge flats, indicating the position of valleys running more or less at right angles to the trend of the ledge flats.

The Southwest Breaker and Chaddock, Little, and Long Bars are the base of lines of æolian hills, once running parallel with the edge of the western and southern Ledge Flats hills.

This proto-Bermudian land must have resembled the Bermudian landscape of to-day, and has been reduced to its present condition by the same causes which we see at work to-day on the islands of the group, and which have acted more vigorously either on the faces most exposed to the prevailing winds, or upon æolian hills of a lower altitude than those of the main island.[1] The proto-Bermudian sounds vary in depth from six to twelve or thirteen fathoms, the deepest being the sound to the north of Three Hill Shoal.

I also agree with Rice and Heilprin that the amount of subsidence must have been "sufficient to account for the depth of water which marks the lagoon and inner sounds," and that "before this subsidence took place probably the entire area now covered by the Bermudian

[1] "The prevalence of powerful winds on the south side would tend to elevate this side of the island, while the opposite side, not feeling this influence in any marked degree, would remain comparatively low and flat. In a period of subsidence the low side would naturally be the first to succumb to the waters, and would undergo submergence long before the elevated slopes. And this is precisely what appears to have taken place in the Bermudas." — Heilprin, Bermudas, p. 42.

archipelago, and much more, were dry land." But I do not think that "it was at this time, doubtless, that the great sand dunes were elevated." On the contrary, I do not imagine the dunes to have been elevated, but to have perhaps been blown to their greatest height in the manner suggested from a broad coral sand beach.

Heilprin adopts the suggestion thrown out by Rice, that these æolian accumulations could only have been formed at a time when large areas of reef, and not a simple atoll ring, were exposed above the water level,[1] while it is perfectly true, as Heilprin says, that all the sand formed at the present day is derived from the destruction of the existing land masses, and not as a product of the disintegration derived from the growing reef, — a statement which by the way hardly agrees with the graphic description of the destruction of the coral reef off the south shore given by him a page or two before.

It does not seem to me necessary that there should have existed very wide areas of coral reefs for the formation of the Bermudian æolian hills. A reef of a width of 1,200 to 1,800 feet, such as are known to exist, seems to me ample to supply the material necessary for the formation of the æolian hills, especially if, as may have been the case judging by the soundings off the reef, there also existed a comparatively wide shallow bank outside of it. Taking the subsidence of the Bermudas as twelve fathoms, this belt could have been a belt of twelve to twenty fathoms, a shallow bank, the wear and wash from which would alone supply a large part of the material needed for the formation of the Bermudian dunes, and carry the topography now prevailing pretty well over the whole of the bank inside the ten or twelve fathom line. In addition, we should of course also have the supply derived from the reef itself. The amount of material which can be supplied from a comparatively small reef and its adjacent bank I saw well illustrated at the Sandwich Islands. A number of dunes were constantly travelling inland from the beach at Spreckelsville, and had covered to a considerable elevation a great part of the isthmus connecting the two islands which constitute Maui. Very high dunes, from 120 to 180 feet, of nearly a mile in width, occur on the shores of the Baltic, the material of which is derived from a comparatively narrow beach range.

I fully agree with those who before me have examined the Bermudas, and who consider that subsidence has brought about the existing condition of the islands and sounds. But that is a very different thing from assigning to the corals now growing the formation of the islands owing to

[1] The Bermuda Islands, p. 46.

this subsidence. That the proto-Bermudian land was of elliptical shape, and owed its existence to the action of winds sweeping over an extensive coral beach, from which was gathered the material which now form the solidified æolian hills of the Bermudas, no one can question. But there is no evidence to show that the original annular coral reef was formed during subsidence. That reef has disappeared, and nothing is left of it except the remnants of the æolian ledges, extending to sixteen or seventeen fathoms outside of the reef ledge flats, ledges which owed their existence to the material derived from it, — the former æolian hills of the proto-Bermudian land. Remnants of such ledges and former æolian hills are the rocks forming the outer ledge flats, the breakers all along the south shore, the Mills Breaker, the North Rocks, the Chub Heads, the South-west Breaker, and others.

The evidence of the extent of the subsidence which has taken place at the Bermudas is very clear. It is based upon the depth of the sounds and of some parts of the lagoon, the existence of æolian rock at a depth of fifty feet below low-water mark, and the excavation of red earth from a depth of forty-eight feet below low-water mark on Ireland Island,[1] and at eighteen feet below low-water mark in the entrance to St. George Harbor. Numerous caves and caverns occur in the Bermudas, which have been fully described by previous writers. Many of them, although extending far below low-water mark, could only have been formed when the islands were at a greater elevation than at the present day. In the caves, as well as smaller ponds or embryo sounds close to the shores, the porosity of the æolian rock, as well as its cavernous and honeycombed structure, is indicated by their connection with the sea. The water rises and falls in the caverns with the tides, and the beat of the diminutive waves against the subterraneous shores of the caves closely follows that of the sea outside.

[1] Sir Wyville Thomson has given a section of the rocks exposed during the excavation for the basin of the dry dock at Ireland Island (Atlantic, I. 319.) Huge stalactites and stalactites covered with Serpulæ extending below low-water mark in some of the caverns clearly indicate the effects of the subsidence. Trunks of the Bermuda cedar have been found in the red earth at a depth of forty-eight feet in the excavation of the dry dock, and have also been dredged from the bottom of Hamilton Harbor in a depth of five fathoms. This is of no great value as evidence, since the stumps may have fallen in from the surrounding hillsides, have floated off, and become water-logged. According to General Lefroy, one of the great bogs of the main island extends to a depth of forty or fifty feet below the sea level, and indicates the depth to which one of the sinks of the proto-Bermudian land reached before the subsidence took place which resulted in the present configuration of the islands.

At the Bermudas we find nothing corresponding to the ocean holes of the Bahamas, unless it be that such cavernous sinks and indentations as occur all along the shores, and which can be detected on the edges of the reefs and ledges, or in the circular areas where the depth is sometimes greater by two to three fathoms than over the adjoining area, may correspond to ocean holes, but only on a smaller scale of depth.

Heilprin thinks "that the height of land in the archipelago was formed during a period of elevation." It seems to me more natural to suppose that the Bermudas were formed during a period of rest, when the level of the reef was stationary, and they were flanked by a broad sand beach with flats perhaps bare at low water. These would supply an abundant material for the formation of such dunes as we now find, and may imagine to have existed on the northern edge of the Bermudas and on the flats which determine the shape of the proto-Bermudian lagoons.

While I fully agree to the all-important part which subsidence has played in shaping the Bermudas as they now exist, I cannot trace any connection between these facts and the proposition that "the existence of an atoll in the present position of the Bermudas is not demonstrable." We certainly have a group of æolian hills formed from an annular ring of coral reefs which flourished when the land was at least seventy feet higher than at present. But the facts we observe on the islands to-day do not shed one ray of light on the question of the Darwinian theory of the formation of atolls. The position of the reef to which the Bermudas owe their origin can only be surmised, — and probably very correctly, — but we cannot state that it was formed during a period of subsidence, and have no data regarding this point. Subsidence has given to these islands their present configuration. But it is begging the question to state that the formation of the proto-Bermudian coral reef, about which Heilprin himself is careful to say we know nothing, if it does "not prove the correctness of the Darwinian theory of the formation of coral islands, measurably sustains it." [1]

We may also agree with him in the conclusion that the present form of the Bermuda Islands bears no relation to the ring of an atoll,[2] that

[1] "The question as to what form of coral structure the Bermudas actually are — what constitutes their fundament, and how they were built to their existing level — still remains unanswered, and possibly we may never be able to answer." — Bermudas, p. 47.

[2] Heilprin says: "In the case of the Bermuda Islands, which limit the field of my own investigations in this direction, I am confident that, whatever may have been the original construction of the region, the present lagoon features have been brought about through subsidence; and this conclusion was reached before me by

the existence of an atoll in the present position of the Bermudas is not demonstrable, and that the lagoons and sounds were formed, as Rice first showed, during a period of subsidence.[1] But granting all this, what is the connection of an island group which according to him has no relation to the ring of an atoll, of an island for which the existence of an atoll cannot be demonstrated, with the Darwinian theory of the formation of coral reefs? How can the conclusions arrived at by Heilprin be reconciled with the following statements made by him: —

"It will be seen that these results, so far as they go, are in absolute harmony with the views which Mr. Darwin entertained regarding the structure of these islands. They do not prove the correctness of the Darwinian hypothesis of the formation of coral islands, but they measurably sustain it; on the contrary, they are largely opposed to the requirements of the substitute theory which has been recently proposed. Elevation and subsidence are both shown to have marked the region in its development, and these conditions are more in consonance with the Darwinian hypothesis than with any other."[2]

Investigators have been carried away by the simplicity of the theory of subsidence propounded by Darwin, and it is only of late years since a mass of observations have been made which could not be explained by the prevailing theory that we have at last realized how complicated the problem is. Heilprin, as well as others before him, has truly said, "We may not yet have fathomed the true method of the formation of coral islands." But I must differ from him *in toto* when he says, "but such evidence as I was able to obtain at the Bermudas failed to convince me of the erroneousness of the time-honored theory of subsidence."[3]

The exploration of the Bahamas and of the Bermudas has brought into prominence a condition of things relating to the formation of coral reefs, the bearing of which had not been realized before. It is perhaps one of the most significant examples of how little we as yet know of the history of the formation of the coral reefs.

Professor Rice, who seems to have been amply satisfied with the subsidence theory." — Bermudas, p. 75.

[1] Heilprin has well stated the conditions of the disintegration of the land when he says: "The difficulty in the problem entirely disappears if we admit subsidence, and, as has already been seen, the positive evidences of subsidence are ample. On no other theory, it appears to me, can the waste of the cliffs on the south shore be explained. The direct evidences of subsidence, moreover, do not come from a single point in the archipelago; they are found from Ireland Island and Hamilton Sound, through the main island, to St. George."

[2] Bermudas, p. 46. [3] Bermudas, p. 21.

EXPLANATION OF THE PLATES.

PLATE I.

Bermuda Islands. Reduced from U. S. Hydrographic Chart, No. 27.

PLATE II.

Fig. 1. The Challenger and Argus Banks to the southwest of Bermuda.
Fig. 2. Section from Somerset Island across the Challenger and Argus Banks. Depth in fathoms, horizontal scale, 1 inch = 10 miles.
Fig. 3. Section north-northeast from North Rock into 1,370 fathoms.
Fig. 4. Section southeast from Castle Harbor into 1,240 fathoms.

PLATE III.

The Bermuda Islands from Gibbs Hill.

PLATE IV.

Mullet Bay, St. George Island. Characteristic Æolian Hills in the background.

PLATE V.

Bare Hills on the North Shore of the Western Entrance to St. George Harbor.

PLATE VI.

Shore of Harrington Sound.

PLATE VII.

Webb's Pond.

PLATE VIII.

North Rock.

PLATE IX.

Deep Cut through Æolian Rock, Warwick.

PLATE X.

Sink, Warwick, South Shore.

PLATE XI.

Sand Dunes, Elbow Beach.

PLATE XII.

Sand Dunes back of Elbow Beach.

PLATE XIII.

Devil's Hole. Characteristic hardened Æolian Rock.

PLATE XIV.

Lagoon near Tuckerstown.

PLATE XV.

Entrance to Hungry Bay.

PLATE XVI.

Æolian Cliffs near Admiralty House, North Shore.

PLATE XVII.

Pulpit Rock off Ireland Island.

PLATE XVIII.

Half-sunken Ledge, North Shore, off Boat Harbor.

PLATE XIX.

Æolian Cliffs, South Shore, near Middleton Beach.

PLATE XX.

Æolian Cliffs, South Shore, Elbow Bay.

PLATE XXI.

Ledges and Islets off Castle Harbor.

PLATE XXII.

Æolian Cliffs with Serpuline Atolls, South Shore.

PLATE XXIII.

Æolian Rock Pinnacles and Serpuline Atolls, South Shore.

PLATE XXIV.

Serpuline Atolls, South Shore.

PLATE XXV.

Serpuline Atolls, South Shore.

PLATE XXVI.

Fringing Serpuline Reefs, South Shore.

PLATE XXVII.

Pitted and Honey-combed Æolian Rocks, Harrington Sound.

PLATE XXVIII.

Ledge showing Passage of Æolian Rock to Base Rock, Boat Harbor, North Shore.

PLATE XXIX.

Pot-holes, Harrington Sound.

PLATE XXX.

Pseudo-Palmetto Stumps, North Shore.